REYNIER ON THE

VOLTAIC ACCUMULATOR

TRANSLATED BY J. A. BERLY

THE

VOLTAIC ACCUMULATOR:

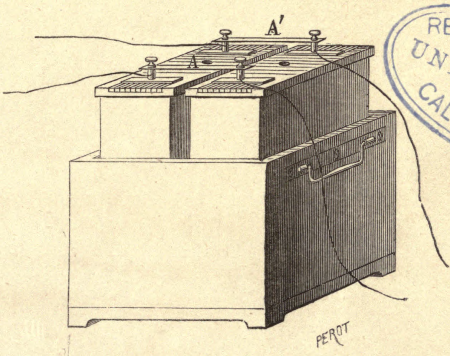
AN ELEMENTARY TREATISE.

By ÉMILE REYNIER.

TRANSLATED FROM THE FRENCH

By J. A. BERLY,

C.E., A.I.E.E., ETC.



WITH SIXTY-TWO ILLUSTRATIONS.

E. & F. N. SPON, 125, STRAND, LONDON.

NEW YORK: 12, CORTLANDT STREET.

1889.

PREFACE.

This Treatise describes, in a didactic manner, the whole of the practical and scientific acquisitions made, in the domain of the Voltaic Accumulator, from Planté to our days. It brings together, summarises, explains, and classifies the notions, theories, and inventions relating to secondary currents, and reviews the principal applications of the latter.

It is an elementary work, with an easy beginning, a sufficiently developed descriptive part, a simple technology, and a practical complement.

The First Part deals with the Principles and comprises two chapters, one devoted to definitions, which have been made as clear as possible; the other to Voltameters or primitive secondary cells. This second chapter ends with a classification of accumulators, the different species of which are comprised under four heads or genera.

The genera, considered in a practical point of view, are of very unequal importance; but a

certain one amongst them, although not in extensive use at the present moment, is destined to play an important part in industry. They should, therefore, all be studied with the same care; and especially as the examination of the various voltametric systems, even including the disused ones, generalises, enlarges the subject, and opens the mind to general views which might remain unperceived by electricians confining themselves to the study of the actually preponderating genus.

The Second Part is devoted to the description of the known accumulators, which are interesting and original. In this part of the work, perhaps, more than in the other parts, I have had to correct some errors of attribution which spread to the detriment of deserving workers. The restitutions and eliminations which had to be made have caused my nomenclature to differ from those previously adopted. I must give an explanation of this fact.

The history of secondary currents does not, up to 1880, present any difficulty: it is given in a most complete form in Gaston Planté's masterly work upon the subject.

The industrial importance of the accumulator, long perceived by clear-sighted minds, becomes evident to everybody in 1881. The unexpected success of Faure's invention excites hopes, emulation, appetites. Innovations, improve-

ments and plagiarisms spread from numerous quarters.

The systems, apparently in great variety, only repeat themselves under various denominations, resulting in a confusion which some have taken advantage of. Some more or less important theoretical or practical works have, in the midst of this confusion, changed paternity.

I have, in the higher interest of truth, separated the inventions and the plagiarisms, and carefully omitted the latter.

Historical rectifications require proving. The theoretical works and the inventions mentioned in this book, are, as much as possible, accompanied with references to their origin—periodical, book, patent, &c. I am thus enabled to claim equivalent references from contradictors.

The attentive reader will acknowledge my impartiality. Should he require to find in this book a known system, he will find it on the condition of seeking for it under its proper designation.*

The Third Part (Technology) contains the formulæ and numerical data necessary for the calculations relating to the utilisation of secondary currents.

* The author does not pretend to be infallible. Some real inventions, not published in France, may have been involuntarily omitted, and he will always be glad to receive any correction or claim accompanied with references.

The applications of accumulators, in the Fourth Part, might have been made the subject of several volumes, but it was necessary to limit their description. The essential notions of each application have been given without going into the details of special mechanical arrangements; in the principal cases, the successive transformations of energy and the coefficients relating to each of them have been indicated. The product of these coefficients is the practical efficiency of the secondary batteries in any given case.

These applications, although in a state of infancy, are indicative of the important place which voltaic accumulation will soon take in industry. Not more in this book than in my previous works has the subject been magnified. How could the range of this novel art, which places in man's hands all the forces of nature, be exaggerated!

ÉMILE REYNIER.

PARIS, 16*th June*, 1888.

CONTENTS.

PART I.

PRINCIPLES.

CHAPTER I.

DEFINITIONS.

CHAPTER II.

VOLTAMETERS.

PART II.

VOLTAIC ACCUMULATORS.

CHAPTER III.

PLANTÉ ACCUMULATORS.

CHAPTER IV.

ACCUMULATORS OF THE PLANTÉ TYPE.—AUTOGENEOUS FORMATION.

CHAPTER V.

ACCUMULATORS OF THE PLANTÉ TYPE.—HETEROGENEOUS FORMATION.

CHAPTER VI.

MISCELLANEOUS ACCUMULATORS.

PART III.

TECHNOLOGY.

CHAPTER VII.

TECHNICAL GENERALITIES CONCERNING ACCUMULATORS.

PART IV.

APPLICATIONS.

CHAPTER VIII.

APPLICATIONS OF ACCUMULATORS.

LIST OF ILLUSTRATIONS.

PART I.

PRINCIPLES.

CHAPTER I.

DEFINITIONS.

VOLTAMETER WITH METALLIC ELECTRODES — SECONDARY ELECTROMOTIVE FORCE: SECONDARY CURRENT — SECONDARY POLARITIES — VOLTAIC ACCUMULATORS, OR SECONDARY BATTERIES.

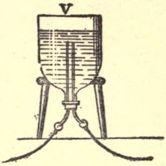


FIG. 1.

Voltameter with Metallic Electrodes.—V (Fig. 1) is a glass vessel containing water acidulated with sulphuric acid. Two platinum wires, not touching each other, are immersed into the liquid, and come out of the vessel through a plug at the bottom.

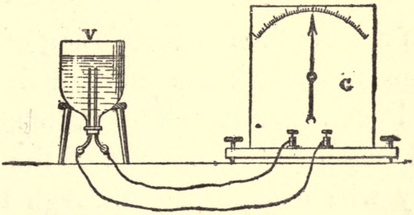


FIG. 2.

If these wires are joined to the terminals of a galvanometer G (Fig. 2) it will be observed that

no current is passing. The two conductors being physically symmetrical towards the liquid, there exists no reason why a difference of potential should be established between them. But this system, which is inert in itself, may become active by the action of an external electrical source.

If we join the two conductors respectively to the two poles of a battery (Fig. 3), inserting the

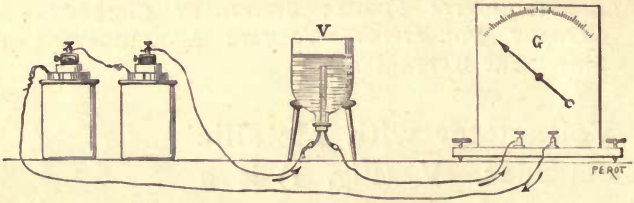


FIG. 3.

galvanometer in the circuit : the needle is deflected and indicates the passage, in the circuit, external to the battery, of a current travelling from its positive to its negative pole.

Within a short time of the closing of the circuit, some gaseous bubbles are emitted from the two immersed conductors. The volumes of gas liberated may give the measure of the quantity of electricity which is passing through the circuit : whence the name of voltameter given to the apparatus, and, in a general manner, to any system of two conductors immersed in an electrolysable liquid.

Secondary Electromotive Force: Secondary current.—The voltameter acquires, by the passage of the current, an electromotive force, and thus becomes a true voltaic couple, called secondary couple, and which gives an electric current called secondary current.

This secondary current can easily be verified. If we disconnect the battery, and join the electrodes of the voltameter directly to the terminals of

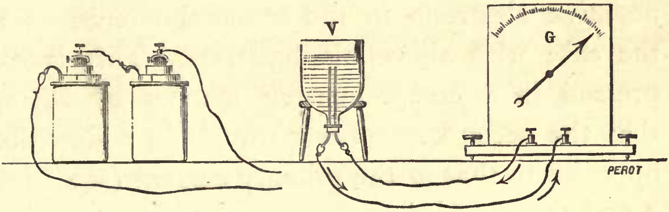


FIG. 4.

the galvanometer (Fig. 4), the needle of the latter is at once deflected, indicating the passage of the secondary current.

Secondary Polarities.—The respective polarities of the two conductors are indicated by the direction of the deflection: the electrodes which were respectively connected with the positive and negative poles of the charging battery have become respectively the positive and negative poles of the secondary couple. Or, in other words: the poles of the electric source

respectively give their names to the corresponding electrodes of the voltameter.

Thus during the charge, the secondary couple is in opposition to the source. The electromotive force of the latter being superior, gives the direction of the charging current, which passes through the voltameter, crossing from the positive to the negative electrode, through the electrolysed liquid. When the voltameter is discharged, the secondary current travels from its positive to its negative electrode in the external circuit, as is the case with all voltaic batteries. This is expressed in a comprehensive manner by saying that the secondary current travels in a direction opposite to that of the primary current (see Figs. 3 and 4).

These phenomena, which are only mentioned in this place, will be explained further on.

Voltaic Accumulators, or Secondary Batteries.—A voltaic accumulator is a voltameter capable of storing a large quantity of electric energy, of keeping it, if necessary, during a certain time, and giving it back without too great a loss in the shape of a secondary current.

Mr. Gaston Planté was the first to invent a voltaic accumulator fulfilling these conditions. (March 1860). Several physicists had, before him, observed secondary currents; some secondary batteries had even been constructed; but

nobody had perceived the possibility of giving these apparatuses the power, the capacity, the permanence and the efficiency necessary to utilisable accumulators. Since Mr. Planté's works, the expression secondary battery has acquired a signification which it did not previously possess; it has become synonymous with the word voltaic accumulator.

Miscellaneous Voltameters.—Numerous voltametric systems may be obtained by varying the nature of the two electrodes, and of the liquid. But all the combinations thus obtained are not fit to produce utilisable secondary currents, or to serve as a basis for systems of accumulators. In fact the number of workable accumulators is limited.

The study of these voltametric systems must logically precede that of the secondary batteries which derive from them. Such is the order of exposition adopted in this work.

Considering the principles of the principal systems of accumulators, their fundamental properties are described under the elementary form of the voltameter. The generæ being thus characterised, the species will naturally become classified under them, and their study may be reduced to the examination of the particularities special to each of them.

CHAPTER II.

VOLTAMETERS.

PLATINUM VOLTAMETER: DILUTE SULPHURIC ACID—LEAD VOLTAMETER: DILUTE SULPHURIC ACID—LEAD VOLTAMETER: SOLUTION OF SULPHATE OF COPPER—LEAD VOLTAMETER: SOLUTION OF SULPHATE OF ZINC—CARBON VOLTAMETER—COPPER VOLTAMETER: SOLUTION OF ALKALINE ZINCATE—VOLTAMETERS WITH ALKALINE AMALGAMS—INDUSTRIAL VOLTAMETERS—CLASSIFICATION OF ACCUMULATORS.

Platinum Voltameter: Dilute Sulphuric Acid.—This voltameter, set up in the form illustrated (Fig. 1), and charged with a battery, gives a secondary current which rapidly decreases to zero. The discharge must be observed as soon as the primary current is interrupted.

The secondary current is, as in all voltameters, due to the chemical reaction of the substances produced by the electrolysis, upon the electrodes and around them. The positive is superficially oxidised, surrounded with oxygen, and some unstable compounds: ozone, oxygenated water, persulphuric acid; the negative is superficially reduced, surrounded with hydrogen and, no doubt, somewhat allied with that metal.

With the exception of the hydrogen and the oxygen respectively fixed upon the electrodes, the products of electrolysis are spontaneously and rapidly decomposed or dissipated; which explains the prompt weakening of the secondary current. If each electrode is covered with a tube, as is done in the experiment of water electrolysis, the hydrogen and oxygen are imprisoned upon the electrodes. The voltameter thus charged may give a current of small intensity but of long duration. It is a kind of rough accumulator, keeping its charge; accumulator feeble but constant; of a limited but definite capacity, of a small but measurable efficiency.

The *platinum sulphuric-acid voltameter* is found at the very early stage of the history of secondary currents. It is curious to notice that Carlisle and Nicholson, when operating upon the electrolysis of water, unwittingly constructed an apparatus vaguely resembling an accumulator. But it is Gautherot who firstly discovered the existence of secondary currents (1801), with platinum and silver wires having been used in the electrolysis of salt water.

A little later on, Ritter constructed his *secondary batteries*, made of metallic discs, separated by washers of cloth, wetted in a salted solution. Volta, Marianini, and Becquerel demonstrated that the secondary currents have a chemical

origin. Mattenci obtained some currents from some strips of platinum previously dipped into oxygen and hydrogen.

Grove next constructed his *gas couple*, composed of two platinum strips dipped in dilute sulphuric acid, and covered with test tubes containing, one some oxygen, the other some hydrogen. From eight to ten of these couples, connected in series, constitute a battery capable of decomposing the water of a voltameter inserted in the external circuit. The spectacle of the analysis of water by its own synthesis is thus obtained, and the volumes of gases in the test tubes can be seen progressively decreasing as they increase in the voltameter.

This beautiful experiment is illustrative of the chemical origin of the secondary currents and of the reversibility of voltameters.

It also demonstrates the similarity of action between ordinary batteries and accumulators. In effect, a Grove battery, charged with gases prepared outside the apparatus, is a real primary battery, chemically prepared; it does not, however, essentially differ, as regards its general properties, from a voltameter charged by the passage of an electric current.

In reality, the primary batteries, chemically charged, cannot all be regenerated by electrolysis; the secondary batteries, electrically charged,

cannot all be regenerated by chemical additions. But these discrepancies of a practical order have nothing absolute.

An accumulator is a battery which can be regenerated by electrolysis. The physico-chemical laws regulating the batteries are applicable to the accumulator. The latter are particular instances of the former.

The *platinum sulphuric-acid couple* offers an elegant demonstration of these fundamental principles. Its proper place is therefore at the beginning of the general study of voltameters, although it is an accumulator which is not utilisable.

Lead Voltameter: Dilute Sulphuric Acid.—This voltameter, the most important of all, supplies the principle of nearly all the accumulators used in the laboratories and industrially. Its properties have been discovered by Mr. Gaston Planté (1859).

Lead being a comparatively cheap metal, the electrodes may be constructed of large sizes, so as to amplify the results to be obtained. The two wires of the classical voltameter are, in this instance, replaced by two large sheets (Fig. 5), placed in a glass jar and isolated from each other in the parts dipping into the liquid.

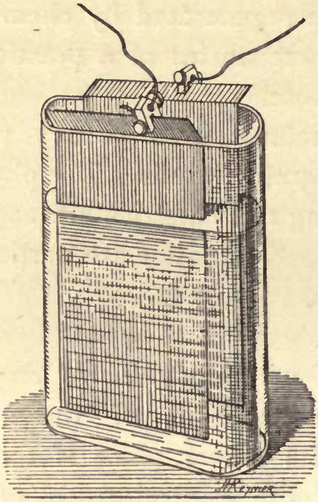


FIG. 5.

When the circuit of a battery is closed upon this voltameter (Fig. 6), the acidulated water is

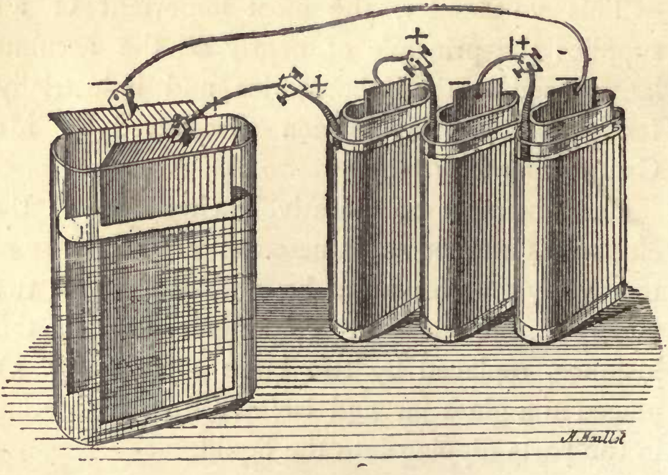


FIG. 6.

electrolysed. The colour of the negative electrode, which was originally the grey colour of lead oxidised in the atmosphere, changes for the lighter tint of reduced lead, and this electrode, in a short time, emits some hydrogen.

At the same time, the oxygen fixes itself upon the positive electrode, the surface of which gets covered with peroxide of lead. The peroxidation attacks the internal face more readily than the external one but, ultimately, equally affects the latter. When all the surface is peroxidated, oxygen bubbles begin to appear; this phenomenon indicates that the voltameter has received all the charge which it is capable of receiving.

Thus charged, the voltameter can act as a voltaic couple, but only for a very short period. If these electrodes are connected to the terminals of a somewhat sensitive galvanometer (Fig. 7), the secondary couple discharges itself in the wire of the instrument, causing the needle to be deflected. During the discharge, the negative electrode gets darker and the positive one lighter.

The double reaction thus enacted is the fixation of one equivalent of sulphuric acid upon each electrode, and the carriage of one equivalent of oxygen from the positive to the negative. That is to say there is, upon the positive electrode:

$$PbO_2 + SO_3 = SO_4Pb + O.$$

And upon the negative electrode

$$* Pb + SO_3 + O = SO_4Pb.$$

When the voltameter is charged anew, the reverse chemical reactions take place, bringing the sulphate of lead to a state of reduced lead on

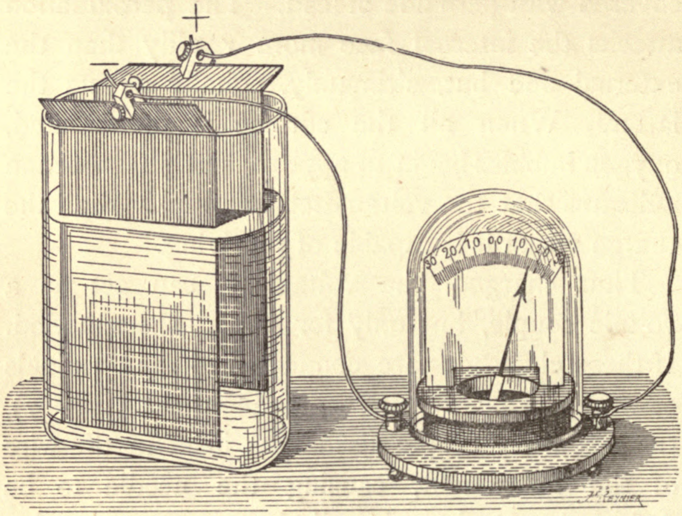


FIG. 7.

the one part and of peroxide of lead on the other part; but this second charge acts on a larger quantity of materials, because the lead and the peroxide (regenerated from the sulphate) are in a permeable state, which allows the electrolytic

* This chemical interpretation of the discharge phenomena is posterior to Mr. Planté's researches.

action to reach the subjacent lead, and to penetrate more deeply, especially on the peroxidised side.

Thus on every new charge, the chemical action reaches deeper. The result is a corresponding increase in the capacity of accumulation. Mr. Gaston Planté has given this progressive increase the name of formation, or forming.

When a voltameter is deeply formed, it is capable of a comparatively large quantity of electricity: it then can rightly be called secondary couple or accumulator.

The forming process is quicker with the positive side than with the negative: hence the necessity of reversing the accumulator from time to time, that is to say of interverting its communication with the source for changing the direction of the charge. Mr. Planté, who is the creator of the lead electrode accumulator, has shown how far the forming process may be carried on by means of charges, discharges, reversions of current and rests methodically practised.

This important question of forming will be discussed in the chapter on accumulators.

Mr. Planté has observed that the electromotive force of voltameters varies to an important extent.

* 'Recherches sur l'Électricité,' page 53 and following.

The study of these variations has been since made, and the measurements of those relating to the more important systems given.*

In the lead sulphuric-acid voltameter, the secondary electromotive force can, after an intense charge, reach 3 volts; it soon decreases to 1·9 or 1·8 volt, and then slowly falls down to zero.

The normal electromotive force of the apparatus is about 1·9 volt. The fugitive increase noticeable immediately after the charge is due to the presence of unstable products such as oxygen, ozone, persulphuric acid, &c., which are spontaneously decomposed.†

Lead Voltameter: Solution of Sulphate of Copper.—This voltameter resembles the preceding one (Fig. 5); its electrodes are made of lead, but the sulphuric acidulated water is replaced by a solution of sulphate of copper.

It can be charged with two Daniell cells or one single Bunsen, since the use of copper salt lowers the secondary electromotive force.

During the charge, the positive electrode is peroxided, and takes the flee tint, as in the acidulated water voltameter; the negative electrode

* "Sur les variations de la force électromotrice dans les accumulateurs," in the work 'Piles Electriques et Accumulateurs,' by E. Reynier.

† Gaston Planté, *loc. cit.*

becomes rapidly covered with a galvanic deposit of pure copper.

If the lead electrodes are new the escape of gaseous oxygen soon appears upon the peroxidised electrode. The metal continues to be deposited upon the coppered electrode as long as there is a supply of it in the electrolyte—the solution becomes gradually discoloured. When the sulphate of copper is entirely decomposed, an escape of hydrogen takes place from the negative electrode. The discharge of this voltameter, like that of the previous one, comprises three phases. The secondary electromotive force is, at first, surelevated: it can reach 1·7 or 1·8 volt immediately after an intense charging; but only 1·5 volt if the primary current is low. In any case the electromotive force rapidly falls to 1·25 volt where it remains during the greatest part of the discharge, to afterwards fall toward zero.

The chemical reactions of the discharge consist in the sulphatation of the two electrodes. There is, on the positive:

$$PbO_2 + SO_3 = SO_4Pb + O;$$

and on the negative:

$$Cu + SO_3 + O = SO_4Cu.$$

The sulphate of copper is dissolved, and restores its blue tint to the liquid.

It must be observed that, in the negative electrode, it is the superficial deposit of copper which constitutes the active part of the electrode, the lead plate only playing the part of support and conductor to the electrolised metal. This conducting support might be made of copper, carbon, or any insoluble metal other than lead. Lead, however, is more suitable for an experimental voltameter, as it does not introduce any complication in the phenomena under observation by the production of an initial and a final electromotive force due to the heterogeneity of the plates.

The sulphate of copper voltameter keeps its charge well enough. Its negative electrode receives its galvanic deposit without previous preparation : the forming of the couple, necessary only to the positive, may then be affected by successive charges, without any reversal.

Notwithstanding this advantage, the sulphate of copper couple has remained inferior to the Planté couple for reasons which will be henceforward explained.

Lead Voltameter: Solution of Sulphate of Zinc.—This voltameter differs from the former one in this respect that its liquid is a solution of sulphate of zinc (Fig. 5).

When it is placed in the circuit of a battery, the positive electrode soon turns flee tint of lead per-

oxide, whereas the negative becomes covered with pure zinc. The gaseous oxygen escapes from the positive electrode when its surface is entirely peroxidised. An escape of hydrogen from the negative takes place almost from the beginning, as the deposited zinc is actively attacked by the liquid. This hydrogen is, therefore, not liberated directly by electrolysis; its escape is due to dissolution of the electrolised zinc. The discharge of this voltameter offers two principal phases.*

In the period immediately following the charge the electromotive force is surelevated to 2·8, 2·6, 2·5 volts; but it soon falls to its normal value which is 2·4 to 2·3 volts and remains, during a certain time between 2·3 and 2 volts. Then it suddenly falls to about 0·6 volt, after which it slowly goes down to 0·4 volt. This second period is longer than the first one. It terminates by a comparatively rapid fall toward zero.

Different chemical reactions correspond to these two periods of the discharge.

During the first, there is sulphatation of the two electrodes, with carriage of one equivalent of oxygen from the positive to the negative as in the former voltameters:

$$\underset{\text{Positive electrode.}}{PbO_2} + \underset{\text{Negative electrode.}}{Zn} + 2SO_3 = \underset{\text{Positive electrode.}}{SO_4Pb} + \underset{\text{Negative electrode.}}{SO_4Zn}.$$

* Emile Reynier, 'Séances de la Société Française de Physique,' 4 Avril, 1884.

This first phase only of the discharge is utilisable. The average corresponding electromotive force is 2·3 volts.

During the second period there is sulphatation of a second equivalent of zinc at the negative electrode, with carriage of one equivalent of hydrogen upon the positive sulphate of lead, which resolves itself into metallic lead and sulphuric acid.

$$\underset{\text{Positive electrode.}}{SO_4Pb} + \underset{\text{Negative electrode.}}{Zn + SO_4H} = \underset{\text{Positive electrode.}}{Pb + SO_4H} + \underset{\text{Negative electrode.}}{SO_4Zn}$$

The average electromotive force corresponding to this second period is about 0·55 volt.

If the voltameter is recharged, the quantity of affected material will be larger than the first time, because the positive lead, firstly peroxidised by the charge, then sulphated by the first portion of the discharge, has finally returned to the permeable metallic state. It is then fit to become more deeply peroxidised during the second charge—there is formation.

We will in the chapter on lead-zinc accumulators further discuss this matter which is of interest owing to their high electromotive force.

We must not proceed further without noticing this feature of the system, in which a complete discharge completely reduced the peroxide of lead into permeable metallic lead; which allows of

forming zinc accumulators pretty quickly and without reversal.

Carbon Voltameters.—Some inventors have attempted to use carbon plates as electrodes, perhaps thinking of utilising the absorbing properties of this material in order to retain and store the gases generated by the electrolysis. But the gas-absorbing capacity of two carbon electrodes corresponds to a very feeble quantity of electricity.

With sulphuric acidulated water, the products of electrolysis retained by two carbon electrodes are complex and unstable. The secondary electromotive force rapidly decreases. Immediately after the charge it can reach 3 volts, but spontaneously falls, within a few minutes, lower than 1 volt.

After a prolonged electrolysis, the positive plate is attacked and becomes rapidly disaggregated; the negative one also becomes altered, though much slower. A blackish mud drops to the bottom of the cell and the electrolyte becomes tinted with carbonated brown materials formed at the expense of the plates.

This destruction of the electrodes occurs, more or less rapidly, with all kinds of electrolytes. Carbon, therefore, does not appear to be a suitable material for use, as electrodes, in a durable accumulator; it could, at the utmost, be used

at the negative only as a support to a galvanic deposit. This explains the general failure of carbon accumulators.

We must, however, mention Mr. Varley's attempt. His accumulator was constituted by carbonised cardboard electrodes immersed in a solution of sulphate of zinc and manganese: the primary current deposited zinc upon the positive, and peroxide of manganese upon the negative electrode.

The secondary electromotive force of a carbon zinc-manganese voltameter may exceed 3 volts; but it soon falls to the neighbourhood of 2 and then much under 2. A persevering study of this system might lead to some practical results if the electrodes, and particularly the positive one, were not condemned to perish in a short time.

Previously to Mr. Varley's attempt, Mr. Maiche had tried (1881) the electrolytic regeneration of Leclanché cells, which are zinc-manganese couples. Nothing has resulted from it.

More recently, Mr. Basset* has tried some accumulators with electrodes made of carbon immersed into pasty electrolisable mixtures composed of metallic oxides impregnated with saline solutions—such as sesquioxide of iron and protochloride of the same metal, protoxide of lead, and

* French patent No. 179,710, 17th November, 1886.

nitrate of lead, &c. The failure of these various combinations might have been foreseen for many reasons, the principal of which is the destruction of the positive electrode.

Copper Voltameters : Alkaline Zincate.— An electric current crossing, between two copper electrodes, a solution of potassium or sodium zincate, oxidises the positive electrode and deposits zinc upon the negative.* Electrolised zinc forms a good galvanic layer, not much attacked in open circuit ; the sub-oxide of copper is, on the other hand, almost insoluble in the liquid. The stable products of the electrolysis being well fixed upon the electrodes, the secondary couple can retain its charge.

Its normal electromotive force is inferior to 1 volt ; it is, as with every voltameter, greater at the moment of interruption of the charging ; its value then depends on the electromotive force of the source and the intensity of the primary current.

The alkaline zincate voltameter seems suitable for the storage of voltaic energy. Messrs. de Lalande and Chaperon, who have discovered its properties, have, some time ago, tried to utilise it in the construction of accumulators. Messrs. Commelin, Desmazures, and Bailhache have

* De Lalande and Chaperon.

recently worked in the same direction with a certain success.

Voltameters with Alkaline Amalgams.—The primary cells which have the highest electromotive forces are those the soluble electrode of which is an alkaline metal (potassium, ammonium, sodium) allied with mercury. It is, for example, known that the electromotive force of the couple potassium amalgam, sulphuric acidulated water, peroxide of lead, is three and a half volts.

A similar secondary couple may be obtained by using a leaden plate as positive electrode, sulphate of sodium as electrolyte, and mercury contained in a porous jar as negative electrode; a platinum wire, dipping into the mercury, constitutes the negative pole of the couple. The secondary currents obtained from this voltameter are of short duration owing to the impossibility of preserving an alkaline amalgam in contact with an aqueous solution. Besides, the available quantity of electricity is small, for the alkaline metals only ally themselves with mercury in feeble proportions.

Industrial Voltameters.—Amongst the numerous voltametric combinations which can be devised by varying the electrodes and the liquids, only a few are utilisable in the construction of accumulators, for we must discard :

1. The systems in which the use of precious materials, such as gold, palladium, platinum, silver, is required.

2. Those necessitating the use of carbon as a positive electrode.

3. The combinations containing more than one soluble metal transportable as a galvanic deposit.

4. The systems the utilisable electromotive force of which is too low.

5. Those emitting corrosive or obnoxious fumes.

Therefore the sulphuric acid voltameters with gold, silver, copper, iron, zinc, aluminium—combinations worked out by Mr. G. Planté—are not industrial. The study of these systems, the characteristic properties of which are described in the master's work, has been laid aside by us.

The seven combinations here studied are the only interesting ones, considered in respect of the production of secondary currents. And yet is it necessary, at the very outset of the study of accumulators proper, to abandon three of them: those with platinum electrodes, with carbon electrodes, and with alkaline amalgams.

Classification of Accumulators.—The voltametric systems capable of storage are thus reduced to the number of four; whence four genera of accumulators.

Each of these genera comprises various combinations, modes of forming, &c., giving rise to numerous species.

The existing accumulators must therefore be divided into four genera, i. e.:

1. The *Lead sulphuric-acid* genus, to which is attached the name of the learned Mr. G. Planté, who discovered it and its first species. The Planté genus is the original one, and most important of all; it is almost exclusively used in industrial practice.

2. The *Lead sulphate of copper* genus, very little in use.

3. The *Lead sulphate of zinc* genus, very little used until now, but interesting owing to its high electromotive force and some special properties.

4. The *Copper alkaline zincate* genus, the first appearance of which has, recently, been noisily proclaimed.

PART II.

VOLTAIC ACCUMULATORS.

CHAPTER III.

PLANTÉ ACCUMULATORS.

PLANTÉ'S ORIGINAL SECONDARY CELLS—SECONDARY CELLS, WITH PARALLEL ELECTRODES—SPIRAL ACCUMULATORS—CHEMICAL ACTIONS IN PLANTÉ'S SECONDARY CELLS—FORMATION — ACCELERATED FORMATION — VOLTAIC CAPACITY — CONSTANTS — AUTOGENEOUS FORMATIONS — HETEROGENEOUS FORMATION.

Planté's Original Secondary Cells.—During the course of his studies on voltameters, Mr. Planté found "that the secondary electromotive force of a voltameter with lead electrodes in acidulated water was more energetic and persistent than that of other metals." * He therefore adopted lead and acidulated water as the essential materials for his secondary batteries (March 1860); this selection was a fortunate one, for, up to the present time, no better electro-chemical system has been discovered.

To obtain a secondary cell of low resistance, Mr. Planté gave its electrodes a large surface. His first couple was composed of two long lead plates placed one upon the other, separated by

* 'Recherches sur l'Électricité,' page 34.

a rough cloth, and rolled into a spiral, an arrangement copied from Offerhaus and Hare's primary battery. The apparatus (Fig. 8) was immersed in a glass vessel containing a solution of one volume of sulphuric acid in ten of water.

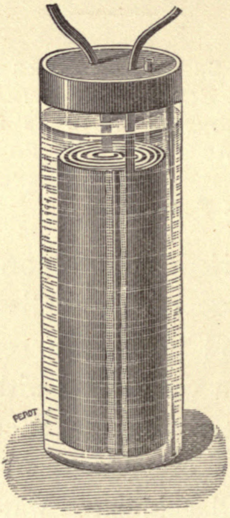


FIG. 8.

The total surface of the two electrodes exceeded one square metre. This secondary couple, after a charge of a few minutes' duration from two Grove cells, gave an intense but short-lived current. The cells thus constructed were soon rendered useless through some internal contacts. The isolating cloth soon become altered in the

acidulated water, and allowed contacts between the electrodes to take place.*

Secondary Cells with Parallel Electrodes.—In order to obviate this inconvenience, Mr. Planté adopted (1868) an arrangement of parallel plane plates, alternately positive and negative, the plates of same polarities being connected together, outside the liquid, by means of external prolongations. The lead plates, placed very near each other, were arranged vertically in a rectangular gutta-percha trough, and separated from each other by means of isolating sticks. The end sides of the trough were grooved internally so as to receive the ends of the electrodes, and maintain the latter in their position. Fig. 10 represents an accumulator of this description.

Fig. 9 is a plan illustrating the details of the arrangement. The positive plates are prolonged in *a*, *b*, *c*; the negatives in *a*′, *b*′, *c*′ ; the first series are connected with the terminal P, and the second one with terminal P′. The conductors from the primary battery are attached at P and P′. B and O are clips between which wires intended to be heated to redness or fused by the secondary current are attached. These clips are in elec-

* The internal contacts are principally due to a kind of incrustation of the partition, which, becoming impregnated with lead and oxygen, creates a derivation between the plates.

trical communication with the terminals P and P′ respectively. A commutator M allows of the

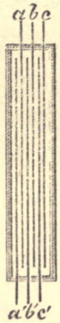


FIG. 9.

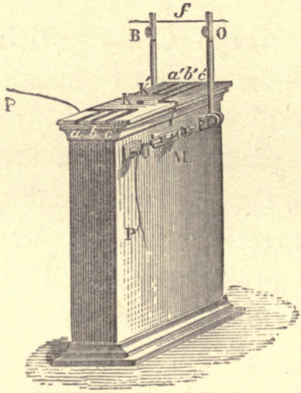


FIG. 10.

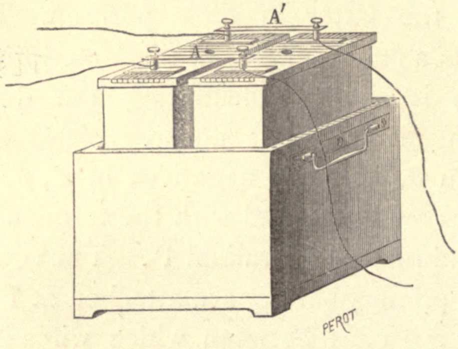


FIG. 11.

discharging current being interrupted or established.

Fig. 11 illustrates two couples constructed in the same manner and joined in tension. This

illustration is taken from a paper by Mr. Planté, published in the 'Annales de Chimie et de Physique' in September, 1868. As far back as that date, this celebrated physicist already employed this arrangement, which is now extensively used in the construction of industrial accumulators.

Spiral Accumulators.—A little later on, Mr. Planté returned to his previous arrangement of spiral electrodes, which has the advantage of being economical of construction, and fitted in glass cells, through which the succession of phenomena can be observed. The rough cloth was then superseded by some indiarubber isolating bands (1872).

Fig. 12 illustrates the couple so modified and

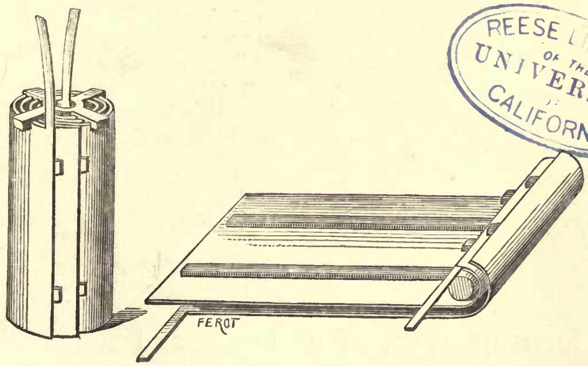


FIG. 12.

its mode of fabrication. Fig. 13 shows it in its glass vessel, and surmounted with an ebonite

cover: the latter is provided with two clips, A, A′, intended for clipping the wire to be heated or fused by the discharging current, and also with

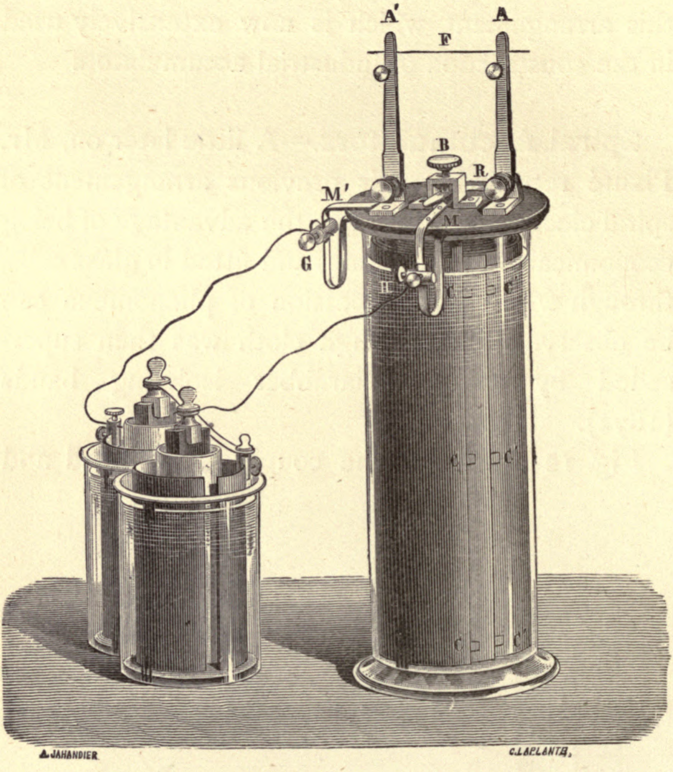


FIG. 13.

an interruptor, R, of a simple and commodious description. A primary battery of two small Bunsen cells charges the apparatus.

This pattern has become almost classical, and hundreds of them have been sold for laboratory

purposes. It is with this form of accumulator that the inventor carried out the original and beautiful experiments which have been described in his masterly researches.

Chemical Reactions in Planté's Secondary Cells.—The chemical reactions, corresponding to the discharge, in Planté's accumulators consist, as we have already said, in the production of two equivalents of sulphate of lead:

$$\underset{\text{Positive electrode.}}{PbO^2} + 2SO_3 + \underset{\text{Negative electrode.}}{Pb} = \underset{\text{Positive electrode.}}{SO_4Pb} + \underset{\text{Negative electrode.}}{SO_4Pb}$$

the charge producing converse reactions.*

* In order to destroy certain errors of attribution it is necessary to recall, here, the history of this theory of the double sulphatation.

Mr. G. Planté had, for a long time, verified the presence of the sulphate of lead in his secondary couples; but considered this sulphate as an accessory product, and not as the normal result of an electrolytic attack. Several authors have, after Mr. Planté, admitted that the electro-chemical actions only took place between the lead and the constituents of water; the sulphuric acid being, in their opinion, a simple auxiliary conductor.

Messrs. Gladstone and Tribe were the first (1882) to admit that the sulphuric acid had a direct action upon the electrodes.

In an Essai sur la Théorie chimique des Accumulateurs ('Société Française de Physique,' 4th April, 1884), the author of this book examined and discussed the various theories expressed at that time, and pronounced for that of the double sulphatation, in favour of which he produced some new and decisive arguments. This paper, vigorously criticised, must have been extensively circulated, for it was reproduced in the 'Séances de la Société,' 'l'Électricien,' 'Le Journal de Physique,' in the book 'Piles Électriques et Accumulateurs,' &c.

It cannot, therefore, be but surprising that certain authors,

The secondary current given by a new couple is of a short duration, because the impermeability of the compact lead limits the electro-chemical action of the charge and of the discharge.

Formation.—We have already explained how the duration of the discharge is increased by successive charges. This increase in the voltaic capacity of the accumulator is the result of a superficial modification of the plates, which, becoming permeable up to a certain depth, allow of the electro-chemical actions to exert themselves upon a greater weight of material. This progressive modification in the structure of the lead has been designated, by Mr. Planté, under the appellation of formation.

If a couple is always charged in the same direction, the positive electrode will become more formed than the negative one, whence the necessity of, from time to time, effecting reversals; that is to say, of interverting the polarity of the electrodes.

Mr. Planté observed that it is advantageous to allow an interval of rest of several days between

---

tardily converted to the theory of the double sulphatation, attribute it to Messrs. Crova and Garbe, who waited until the 1st January, 1885 ('Comptes Rendus de l'Académie des Sciences') to proclaim it; or to Mr. Tschelltzow, who only contributed (ditto, 8th June, 1885) a thermo-chemical verification, already foreseen, by measuring the heat due to the formation of the peroxide of lead.

the reversals, so as to give the oxide and the reduced metal deposit time to acquire the crystalline texture, and to firmly adhere to the surface of the electrodes. The intervals of rest, of which mention is made above, between the changes of direction of the primary current, have a considerable influence. Thus a secondary couple, the plates of which have been submitted, during a few consecutive hours, to the action of the primary current, being abandoned to itself for a month, without being discharged, and then re-charged in a contrary direction at the end of that time, will give a discharge of a duration double that which it formerly had." *

This increase in the voltaic capacity by means of rest appears to be the result of the action of a local couple constituted by the peroxide of lead and the subjacent metallic lead couple, † the chemical action of which would be expressed by the equation.

$$PbO_2 + Pb + 2SO_3 = 2SO_4Pb.$$

One equivalent of peroxide of lead thus produces two equivalents of sulphate, which are capable of giving, by a subsequent charge, two equivalents of peroxide or of reduced lead.

As regards the solidity and the good adherence thus obtained, it can no doubt be explained by

* 'Recherches sur l'Électricité,' p. 35.
† Gladstone and Tribe.

the production in the acidulated water, of an over-saturated solution of sulphate of lead, which slowly deposits the salt upon the electrodes in a state of firmly aggregated crystals.* This aggregation of the sulphate, therefore, is obtained by a chemico-physical process analogous to that to which the setting of cement is due, according to Mr. Le Châtelier's new theory.

Mr. Planté has given out the method to be followed for forming his couples by means of successive charges and discharges, with prolonged rests and reversals effected at opportune times.†

Accelerated Formation. — The ordinary method is long, expensive, and almost impracticable industrially. The aim of inventors who, after Mr. Planté, attempted to perfect the accumulators, has been especially to shorten and to consolidate the formation.

Mr. Camille Faure was the first to succeed in rapidly obtaining considerable voltaic capacities (1880). With him, the accumulators enter into an industrial era. The brilliant results obtained by Mr. Faure and proclaimed by his co-worker ‡

* Emile Reynier.

† *Loc. cit.*, pp. 53, 54 and 55.

‡ 'Comptes Rendus de l'Académie des Sciences' Meeting of the 18th April, 1881 : Note sur la pile secondaire de Mr. C. Faure, par E. Reynier. 'Société d'Encouragement' Meeting of the 22nd April, 1881 : Lecture and Experiments on the Faure Battery by the same.

stir the emulation of inventors who, in large numbers, come and try their hands at a subject almost neglected up to then.

Mr. Planté himself recommences the study of his accumulators with a view to their practical applications, and discovers new means of accelerating their formation.

The celebrated physicist at first recommended the heating of the couple during the passage of the primary current.

". . . this elevation in the temperature has for its effects, by expanding the metallic pores of the lead (metallic plates), to facilitate the penetration of the electrolytic action; that is to say, the deep peroxidisation of the positive plate, and, consequently, the reduction at the same depth, of the negative plate oxidised by a previous action. It also facilitates, by the contrast of the succeeding cooling, the crystalline aggregation of the peroxide of lead and of the reduced lead, and which constitutes a state of things favourable to the production of the secondary current, and to the conservation of the charge produced.

"The duration of formation of secondary couples is thus considerably shortened, at the same time the qualities which render them valuable in numerous applications are maintained." *

This process has not been put in industrial

* Gaston Planté, French patent No. 144,101, 25th July, 1881.

practice. Mr. Planté appears to have abandoned it for the following one, which is used with much success by several makers.

"This process consists in simply submitting the secondary couples to a kind of deep cleansing by means of nitric acid diluted with the half of its volume of water, leaving them immersed in the liquid during twenty-four to forty-eight hours. The couples are then emptied, thoroughly washed, filled with a solution (one tenth) of dilute sulphuric acid, and submitted to the action of the primary current. A portion of the lead is no doubt dissolved during the immersion in nitric acid, but not sufficient to apparently reduce the thickness of the plates; and owing to the metallic porosity the chemical action is not confined to the surface of the plates, but reaches their interior; it creates new molecular intervals, and consequently facilitates the ultimate penetration of the electrolytic action of the primary current. Secondary couples thus treated can, in eight days, after three or four reversals, give discharges of long duration, whereas the same results could only be obtained after several months of the ordinary treatment." *

Voltaic Capacity.—The specific voltaic capacity of well formed Planté accumulators

* Gaston Planté, 'Comptes Rendus de l'Académie des Sciences,' 28th August, 1882.

depends on the thickness of the electrodes. The thinner the electrodes the greater the capacity, but also the greater the fragility of the couples. With electrodes one millimeter in thickness, and of sufficient stiffness, Mr. Planté obtains a capacity of about 36,000 coulombs (10 ampère-hour) per kilogramme of lead.

Constants.—The utilisable normal electromotive force of a Planté or similar pattern accumulator is about 1·9 volt; but it is higher in the first moments after the charge, and particularly during the charge itself.

This fugitive surelevation of the secondary electromotive force increases with the intensity of the charging current and the electromotive force of the source; it is due to the presence of unstable bodies which spontaneously decompose after the interruption of the charge. The stable bodies only remain: the reduced lead, the peroxide of lead and the sulphuric acid, the definite reactions of which correspond to the normal discharge, under a fall of potential of 1·9 volt.

The internal resistance of Planté's accumulators is low owing to the good conductivity of the liquid; and the lower in proportion to the greater surface of the plate. Forming, when it does not exceed certain limits, lessens the resistance. The influence due to the reduction of the distance between the electrodes is less than that due to

the development of their surfaces and to their degree of formation.

A formed couple the distance between the electrodes of which is 5 millimeters, and the total surface of the said electrodes 50 square decimeters (800 sq. in.), has a resistance of 0·04 to 0·06 ohm.

This low resistance of the Planté accumulators renders them fit for the production of currents of greater intensity than the most energetic primary batteries.

Autogeneous Formation: Heterogeneous Formation.—After the study of Planté accumulators comes the description of various species of accumulators belonging to the same genus.

These species, already numerous, will be grouped under two principal series, according to their method of forming. (It is known that the formation consists in rendering accessible to electrolysis a certain weight of active material upon each electrode.)

In Planté's original accumulators and those of the same description, the active materials are issued from the metal itself of the electrodes: these accumulators belong to the first series, and shall be designated as autogeneous formation accumulators.

The other species belong to the second series: that of heterogeneous formation accumulators.

CHAPTER IV.

ACCUMULATORS OF THE PLANTÉ TYPE: AUTOGENEOUS FORMATION.

ACCUMULATORS, SURFACE FORMATION—FOLIATED ACCUMULATORS—TOMMASI ACCUMULATORS—DE KABATH ACCUMULATORS—LEAD WIRE ACCUMULATORS—SIMMEN ACCUMULATOR—SIMMEN AND REYNIER ACCUMULATORS—LEAD SHOT ACCUMULATORS—PLAITED ELECTRODE ACCUMULATORS—INCREASE BY FORMATION—INCREASE BY DISCHARGE—GROSS INCREASE—QUICK AUTOGENEOUS FORMATION, COMPRESSED BY THE INCREASE—REYNIER ACCUMULATORS—ELECTRODES RENDERED PERMEABLE BY THE ELIMINATION OF AN AUXILIARY METAL—MONNIER ACCUMULATOR—SULPHURETTED ELECTRODE ACCUMULATOR.

Accumulator Surface Formation.—To render accessible to the action of electrolysis a given weight of active material, such is the object of formation. The desired weights can be obtained by giving the electrode surfaces a great development: a superficial attack will then be sufficient to secure the required mass. This is the surface formation which is effected in accumulators with laminated electrodes, lead wire, lead shot electrodes.

One kilogramme of lead, laminated to the thickness of 1 millimeter, develops a surface of

18 square decimeters. The surface being inversely proportional to the thickness, lead laminated to $\frac{1}{10}$ millimeter thickness will develop a surface of 180 square decimeters per kilogramme. The Tommasi and de Kabath accumulators are based on this principle.

*Tommasi Accumulators.** — The electrodes of the Tommasi accumulators are vertical leaden plates about 2 millimeters thickness, and provided with cross vertical partitions, cast with the plates, and making with the latter an angle of 30 or 40 degrees. The spaces of about 5 millimeters, left between these partitions, are filled with lamellated lead sheets about $\frac{1}{10}$ millimeters in thickness.

The formation rapidly oxidises these lamellated sheets at the positive pole, and converts them into spongy masses which are retained on their supporting plates owing to the inclination of the compartments. The positive electrode only is formed, so it is necessary to reverse, at least once, the direction of the charging current in order to successively form the two electrodes. These reversals are compulsory with all accumulators of the Planté genus of autogeneous formation.

De Kabath Accumulators.—In these accumula-

* French patent No. 143,555, 3rd September, 1881, taken out by La Société Universelle d'Électricité Tommasi, for Perfectionnements dans les piles secondaires.

tors, the electrodes are made of very thin leaden strips, horizontally superposed in a narrow leaden box (Fig. 14); all these strips are made

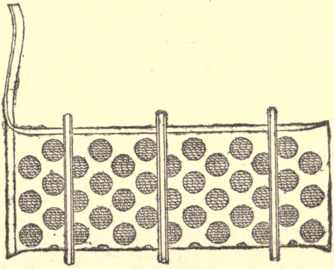


FIG. 14.

to be in intimate contact with the boxes by means of an energetic compression exerted on the vertical edges of this perforated plate. In order to prevent the strips from screening one another, the inventor has given every other one an undulated shape: whence the name of fluted accumulators.

The pattern most in use (Fig. 15) weighted 36 kilogrammes, distributed as follows:

10 positive and negative electrodes	21 Kg.
Sulphuric acidulated water $\frac{1}{10}$	6 „
Wooden case lined with ebonite	3 „

The formation is effected by a series of successive charges and discharges, with a few reversals and is quickened by adding, during the first

two hundred hours, $\frac{1}{100}$ of nitric acid to the solution.

A voltaic capacity of 12,000 coulombs or 3·33

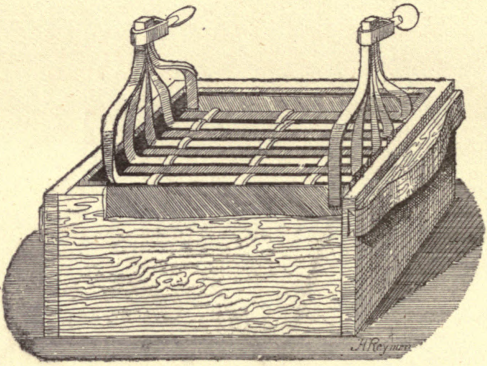


FIG. 15.

ampère-hours per kilogramme of lead is obtained after 500 hours' forming.

Lead Wire Accumulators. — One kilogramme of lead, drawn to a diameter of one millimeter, develops a surface of 35 square decimeters; the surface developed for a given weight of lead is in an inverse ratio to the diameter of the wire.

In the first lead wire accumulator, the electrodes were made of cables * which arrangement had this advantage that all the parts of the

* Emile Reynier, French patent No. 142,777, 16th April, 1881.

electrode were in thorough communication with the external charging circuit.

Mr. Tommasi * has wound some 1 mm. diameter leaden wires round leaden plates 2 mm. thick.

Messrs. Arnold and Tamine have used leaden wires of different forms: concentrical helixes, spiral plates, small straight lengths soldered at their ends to a leaden frame, &c.

These various systems, incompletely worked out, had several defects, the most serious of which was the high price of lead wire.

Simmen Accumulator.—Mr. Simmen has invented a very ingenious process for the economical production of leaden wire of all diameters and lengths.

This process consists in pouring some melted lead in a heated metal box, the bottom of which is provided with holes of convenient shapes and sizes. The melted metal flows through these holes and is suddenly cooled by falling into a tank full of water. The wire so manufactured does not possess the regularity of drawn-wire; it is more or less coarse, and all its parts are so interwoven with each other that it would not be suitable for ordinary purposes; but it is perfectly suitable to the construction of accumulators.

* Société Universelle d'Électricité Tommasi, French patent No. 143,101, 10th August, 1881, Pile secondaire Nouvelle.

Mr. Simmen has made some electrodes with his wire. In his first plates (Fig. 16), the spun

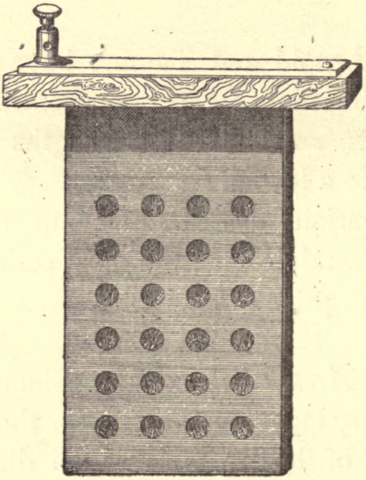


Fig. 16.

wire was encased in a box made of laminated lead. This box screened a large proportion of the wire, thus reducing to a considerable extent the advantage of a great surface development; its cost destroyed the economy realised in the manufacture of the wire. These inconveniences of the perforated box are not atoned by any increase of solidity; on the contrary, this envelope is rapidly formed and infallibly gets cut toward the level of the liquid, allowing the fibrous mass which it supports to fall at the bottom.

Mr. Simmen had to abandon this unfortunate reminiscence of the de Kabath accumulator. With the assistance of another inventor, he tried to find a better use of his wire, which proved such a cheap finely divided lead.

Simmen and Reynier Accumulators.* —The supporting cage or box being condemned, means had to be found for aggregating the leaden wires. The cabling and the coiling were out of question with such intricate masses of material. But a close examination of some specimens soon led to the discovery of a precious property which allowed of its being utilised.

Simmen's wire is not smooth. Seen by the microscope it is composed of a succession of tear-shaped drops, of a series of irregular bodies alternately inflated and depressed. These rugosities are advantageous; they increase the surface and render the wire fit for felting. A handful of material, kneaded with the hand and then flattened with a hammer, at once agglomerates into a felted mass of a certain strength.

It was therefore thought that fibrous materials, submitted to energetic compression within solid matrixes, would produce some resisting felts. The trial was successful. A parcel of threads, compressed in a press or stamp, becomes a solid

* French patent No. 168,155, 8th April, 1885, 'Électrodes d'accumulators en plomb.' Émile Reynier, and Adolphe Simmen.

plate, which is, however, permeable, and containing millions of cells.

The mean density of the plates depends upon ths pressure exerted upon them. This density has been regulated to 8, so that the empty spaces or cells occupy about one-third of the plate. Notwithstanding the apparent disorder of these lumps of threads which are crushed by compression without any preparation whatever, the solid and the hollow parts happen to be regularly distributed; haphazard has its laws.

The capillary structure of the felts secures a quick forming, a large voltaic capacity and a good internal conductivity. These properties can be exalted or attenuated at will: the strength and the duration of the electrode increase with the thickness of the thread used; the rapidity of forming and the voltaic capacity, on the contrary, increase with their slenderness; whence the possibility of securing, according to the requirements of the cases, one or the other of these desiderata.

In practice, the threads of the negative and positive electrodes are made of $\frac{2}{10}$ and $\frac{5}{10}$ mm. diameter respectively.

A leaden frame, provided with suspending appendices, is cast round the felted sheet, acting as a support and a conductor to it (Fig. 17).

The following figures apply to a specimen of felted plate having been in ordinary use.

Width of the plate	140 millimeters.
Total height	245 "
Thickness	4 "
Weight of the felt	700 grammes.
Total weight	1300 "
External surface of the electrode	5·4 square decimeters.
Total developed surface, positive electrode	50 " "
Total developed surface, negative electrode	125 " "
Voltaic capacity per pair of electrodes	17 ampère-hours.
Voltaic capacity per kilogramme of felt	12 " "
Voltaic capacity per kilogramme of plate	7·3 " "

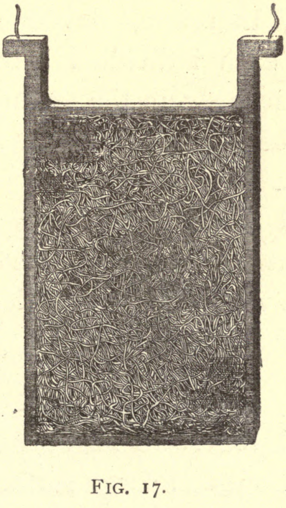


FIG. 17.

Felts of indefinite lengths can be obtained by laminating. The wire lead, on coming out of the

draw-plate, falls on an endless travelling table, which takes it between a pair of cylinders where it is felted at the requisite thickness. This process, more rapid than the compression with matrixes, gives some cheap leaden felts which will find use in the construction of secondary batteries.

Lead Shot Accumulators.—1 kilogramme of lead divided in spheres, 1 mm. diameter, develops a surface of 52 square decimeters. The surface is in an inverse ratio to the diameter of the spheres; shot much smaller than 1 mm. can easily be obtained.

Fine shot, therefore, develops an enormous surface, but each individual shot can only participate, efficaciously, to the voltaic actions, on the condition of being in good electric communication with the pole.

Fine lead shot has been used by Mr. d'Arsonval, at the positive plate of a secondary couple which will be hereafter described with the sulphate of zinc accumulators.

Plaited Electrode Accumulators.—Accumulator electrodes of large surface, and the parts of which are totally accessible to the electrolytic actions, can be obtained by plaiting, concertina fashion, some laminated lead strips. This

arrangement is simpler, and more effective than the layers of foliated lead or the encaged strips.

In order to increase the strength and the life of plaited electrodes, Emile Reynier, at first reinforced them by means of a hemming, or ribs transversal to the plaiting cast with the plate before its being plaited. (Fig. 18).

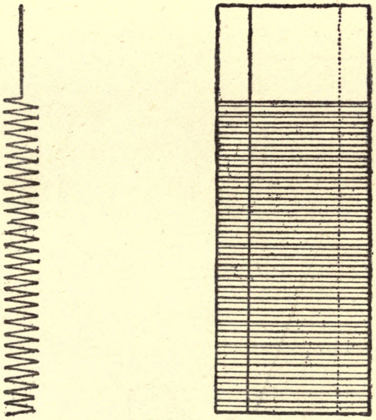


FIG. 18.

The transversal zones, thus reinforced, connect the parts of the electrodes rendered fragile by the forming;* cuts in the simple parts can no longer cause the breaking of the electrode.

In an old and well-known pattern of plate, the sheet of laminated lead, ½ mm. thick, was first

* French patent No. 153,915, 23rd February, 1883, 'Perfectionnements aux Accumulateurs Électriques.'

trebled by a double transversal folding (Fig. 19) then longitudinally plaited. The edges of the vertical folds were then split along the greatest part of their height so as to give access to the electrolytic action to the internal surface of the

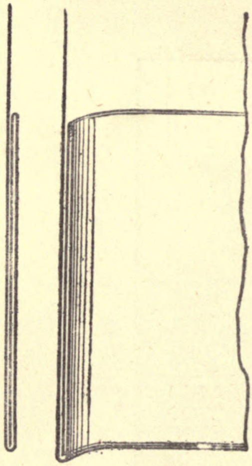


FIG. 19.

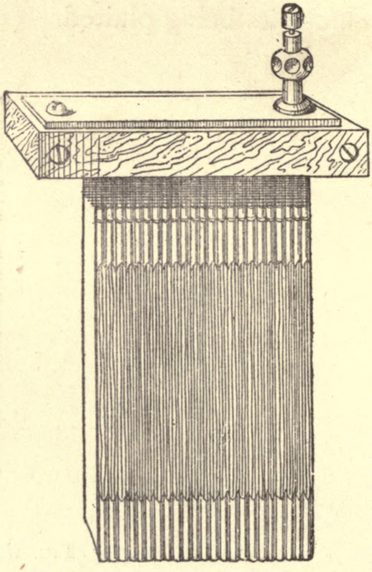


FIG. 20.

plaited plate (fig. 20). The slits stopped at two or three centimeters from the edges of the three-fold part, leaving two reinforced zones.

The plate was suspended in the liquid by means of a top cross-piece resting on the top of the cell. This arrangement, which has been copied by several makers, has the advantage of isolating the electrodes from the *débris* falling at

the bottom of the cell, and of reducing the weight bearing on the bottom of the cell.

The formation and use of the plaited electrodes give rise to an important phenomenon, a development in the shape of a fan (Fig. 21),

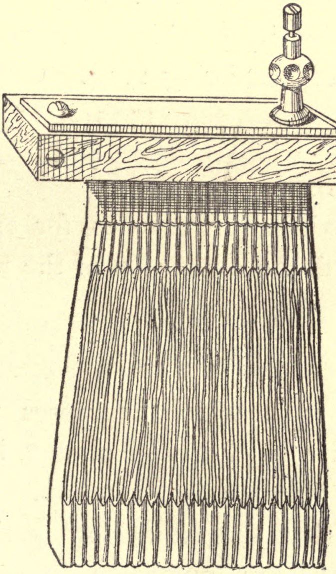


FIG. 21.

development studied by the author, and designated by him "increase" (foisonnement). This phenomenon, which we will explain, occurs in all the accumulators of the Planté genus; but it is more visible with the plaited plates, which are easily distended.

Increase by Formation.*—When an ordinary plate of ordinary lead is being formed into a positive electrode of accumulator, its weight increases and its mean density decreases.

In effect, a proportion of the metallic lead becomes peroxidised by fixing some oxygen. One gramme of lead gives 1·15 grammes of peroxide. The density of this peroxide is only 9·4, that of compact lead being 11·4. One volume of lead, therefore, gives $1 \times \frac{1 \cdot 15 \times 11 \cdot 4}{9 \cdot 4} = 1 \cdot 39$ volume of peroxide.

If the peroxidisation reaches, for example, the half of the lead, the expansion of the whole is

$$\frac{1 + 1 \cdot 39}{2} = 1 \cdot 19.$$

The number 1·19, which expresses the ratio of the final volume to the original one, is the coefficient of cubic increase by formation.

Assuming that the expansion is the same in every direction, the expansion in one direction (lineal increase) is the cubic root of the volume expansion :

$$\text{Coefficient of lineal increase of formation} = \sqrt[3]{1 \cdot 19} = 1 \cdot 06.$$

Owing to the plasticity of the materials, the lineal increase is not equal in every direction; it is

* 'Sur le foissonnement du plomb dans les accumulateurs,' by Émile Reynier. Société Française de Physique, 20th March, 1885, meeting; and 'l'Électricien,' 11th and 18th April, 1885.

greater in the directions offering less resistance. The coefficient expressing it is, therefore, only an average.

When a formed positive is reduced in order to make a negative of it, its volume does not vary to any great extent. The increases of formation are therefore nearly equivalent for the two electrodes.

Increase by Discharge.—The discharging of an accumulator produces, upon the two electrodes, some sulphate of lead, heavier and less dense than the peroxide of lead and the spongy lead: the result is a new increase in the volume of the plates.

The expansion of active material is calculated from the following data:

1 part of lead gives	1·46 parts of sulphate of lead.
1 „ peroxide gives	1·27 „ „
The density of formed lead (spongy) is ..	8·2 (*)
„ peroxide of lead is	9·4
„ sulphate of lead is	6·2

Whence

$$\text{Cubic expansion at the positive} = 1{\cdot}27 \times \frac{9{\cdot}4}{6{\cdot}2} = 1{\cdot}93$$

$$\text{„ „ negative} = 1{\cdot}46 \times \frac{8{\cdot}2}{6{\cdot}2} = 1{\cdot}93$$

The utilisable discharge stops before the complete sulphatation of the spongy lead and of the

* Variable, owing to the plasticity of the material.

peroxide, because the sulphate, which is not conductive, progressively increases the electrical resistance of the active materials. The half only of these materials may act in the discharge.

We have recently assumed that the formation had only attacked one half of each electrode; the increase by discharge, therefore, finally exerts itself upon one quarter of the total weights. The coefficients are, therefore:

$$\text{Coefficient of cubical increase by discharge} = \frac{1{\cdot}93+3}{4} = 1{\cdot}23$$

$$\text{,, ,, lineal ,, ,,} = \sqrt[3]{1{\cdot}23} = 1{\cdot}07$$

Gross Increase.—When the accumulator is recharged, the active materials have a tendency to return to the smaller volume which they had before the discharge, but the metallic supports, which are not much elastic, remain distended; the permeable materials, therefore, become depressed, hollow, more porous. The voltaic capacity of the accumulator would be limited by this phenomenon if it was not already so owing to the low conductivity of the sulphate.

The supports remaining distended after the discharge, the final increase or gross increase, is the product of the increase by formation by that by discharge, or, in the foregoing case:

$$\text{Coefficient of gross cubical increase} = 1{\cdot}19 \times 1{\cdot}23 = 1{\cdot}46$$

$$\text{,, ,, lineal ,,} = \sqrt[3]{1{\cdot}46} = 1{\cdot}134$$

These enormous increases are calculated on the

hypothesis of an autogeneous formation couple realising the maximum voltaic capacity established by theory*—that is to say about 32 ampère-hour by kilogramme of lead. But the largest capacity of autogeneous formation accumulators is 16 ampère-hours per kilogramme. For this latest figure the gross increases, cubical and lineal, are, respectively, 1·23 and 1·07.

According to calculation, the gross increases are equal in the two electrodes; but in practice that of the positive is greater than that of the negative, the forming of the positive one gradually increasing to a greater depth than that of the negative.

Expansion of active materials being a common feature to all electrodes belonging to Planté's genus, this fact must not be lost sight of in the construction of accumulators. The tendency of this phenomenon is to produce some extension, warping, and other motions often resulting in internal contacts and breakage of the plates.

Quick Autogeneous Formations, Compressed by the Increase.—On the other hand it has been, as we will see, possible to utilise increase for compressing, aggregating, and retaining the formed materials.

* See 'Consequences pratiques de la théorie chimique des accumulateurs,' in 'Piles Électriques et Accumulateurs.'

*Reynier Accumulators.** — The plaited electrodes, which were the means of studying the importance of the increase phenomena, have benefited from this study.

The inventor thought that by limiting the lateral expansion, he could produce a strong compression of the superficial materials against the internal walls of the folds—and that those materials, thus pressed against their support, would become more active. He certainly obtained greater voltaic capacities by connecting the folds of the electrodes by means of transversal autogeneous soldering, but the latter are difficult of execution, costly, and weak. A much better result was obtained with the new electrode, illustrated in Fig. 22 in its non-formed state, and in Fig. 23 in its formed and increased state, and in which the frame is a solid casting.

The active portion of the electrode is made of a sheet of laminated lead 0·65m. long by 0·17m. wide and ½ mm. thick. In the midst of this plate a lozenge, the vertical and horizontal diagonals of which are respectively 0·12m. and 0·11m. is cut out and the plate is then plaited. The expansions of the plate converge toward the hole thus made.

The plaited plate is placed in a cast iron

* Addition to French patent No. 153,915. 'Électrodes d'accumulateurs à compression interne par foisonnement,' see 'l'Électricien,' 10th October, 1885.

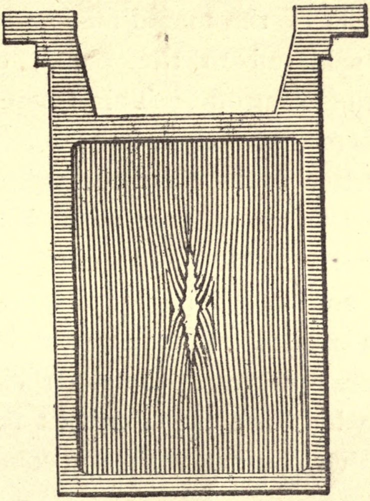


FIG. 22.

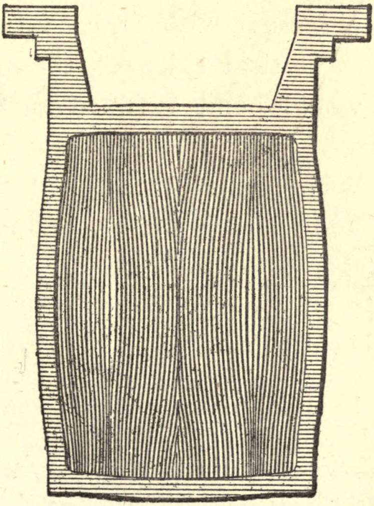


FIG. 23.

mould, and melted lead being poured in it, the space which has been left between the pannel

and the walls of the mould fills, and the casting, which is soldered to the panel, constitutes a frame for the electrode. This frame is provided with two ears cast with it, and acting as supports and conductors to the electrode.

This cast frame physically and mechanically strengthens the electrode in a much more effectual manner than the hemming or ribs of the old plates. It resists to transversal increase, and energetically compresses the superficial permeable materials which are thus brought to an intimate and extensive contact with the conductive parts of the plate.

The converging of the folds toward the central aperture increases with the formation; this relieves the vertical sides of the frame, which otherwise would bend outward to too great an extent.

The following data refer to the plate said "normal" and which is the most in use :—

Width of frame	140 millimeters
Height	220 „
Total height of the plate	255 „
Thickness	5 „
Weight of the plaited pannel ..	600 grammes
Total weight	1200 grammes
External surface of the electrode ..	5 square decimeters
Total developed surface	21 „
Voltaic capacity per pair of plates	14 ampère-hours.

The voltaic capacity of the plaited plate is about 12 ampère-hours per kilogramme; but the

dead weight of the frame being equal to that of the pannel, the capacity of the whole is only 6 ampère-hours per kilogramme of plate.

In order to obtain a better specific utilisation of the lead it is necessary to reduce the proportional weight of the frame. This has been done in another pattern of electrode, the particulars of which are as follows:—

Length of frame	125 millimeters
Height	500 "
Total height of the plate	570 "
Thickness	5 "
Weight of the plaited pannel ..	1·500 grammes
Total weight	2·250 "
External surface of the electrode	13 square decimeters.
Developed total surface	50 "
Voltaic capacity per pair of plates	36 ampère-hours

In this case the voltaic capacity of the whole reaches 8 ampère-hours per kilogramme of plates.

The forming is carried out according to Planté's method; it is comparatively quick, and especially if, as recommended by him, care is taken to previously attack the electrodes with nitric acid. This operation may be energetically pushed, as, owing to the structure of the plate, the fall of the superficial materials is not to be feared, the said materials being firmly secured by compression.

The distance between the folds is regulated in such a manner that the average density of the active portion may be from 6 to 6·5. The density

of compact metallic lead being 11·4, there is at first a certain amount of play between the folds; but the increase fills the gaps, cements the strips, and gives the four sides of the frame an apparent convexity which is an indication of a strong internal compression (Fig. 23).

The electrodes are suspended and bear on a frame of varnished wood placed on the cell; to each of them a length of nickel wire is soldered, and this wire is secured by a screw into the corresponding hole of a nickelled brass collector.

The isolation of the plates is secured by means of vertical indiarubber rings, or, what is better, by wooden or ebonite forks (Fig. 24).

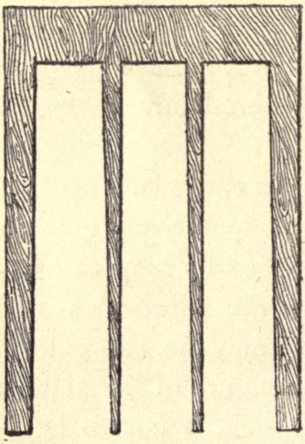


FIG. 24.

The number of plates is an odd one, so that the first and the last ones are negative.

The small pattern, with five normal plates (Fig. 25), is mounted in a glass jar. The larger size patterns, with 9, 13, or 27 plates, are mounted in sandstone jars lined with a bituminous varnish

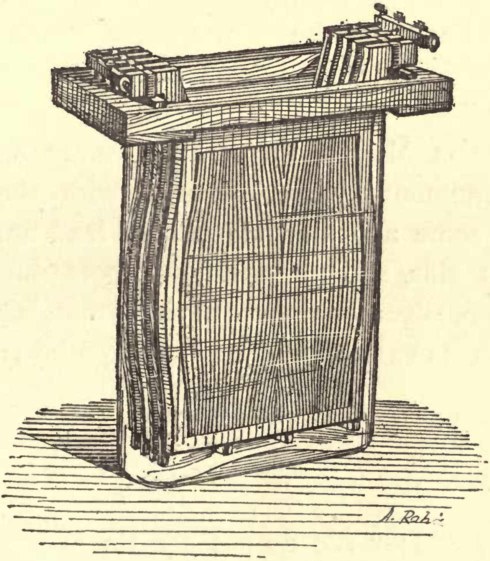


FIG. 25.

which renders them impermeable to sulphuric acidulated water. All these accumulators can be taken to pieces for inspection, renewals, &c., without the assistance of a specialist.

The large plates of 2·250 k, mounted in the same manner, constitute the series of deep accumulators.

Electrodes rendered Permeable by the Elimination of an Auxiliary Metal.—Thick plates may be rendered permeable by alloying to the lead an auxiliary metal which is afterwards eliminated.

In a patent already mentioned,* Mr. Tommasi claims "the use of a spongy metal due to the electrical decomposition of an alloy of lead and tin."

Later on, Messrs. Fitzgerald, Crompton, Biggs, and Beaumont † have indicated, with the same object, some alloys or mixtures of lead and other metals: zinc, sodium, antimony, potassium, iron, cadmium, silver, or several of these metals. They mention, as examples, the following alloys:

2 to 4	parts	of lead	with	1 of antimony
8	"	"	"	1 of zinc
300	"	"	"	50 of zinc and 1 of sodium.

They add: "We do not use tin in any of our alloys, because we found that it could only be eliminated with great difficulty—and that, should any tin be left when the plates form the electrodes of a battery, it will slowly dissolve, be deposited, and create false contacts between the electrodes."

The results of their researches have not been made known by these inventors.

* No. 143,555, 3rd September, 1881.

† French patent No. 149,200, 25th May, 1882. Perfectionnements dans les piles secondaires.

Monnier (Denis) Accumulator.—Mr. Denis Monnier appears not to have been aware of the aforementioned experiments* when he tardily patented his lead-alloyed electrodes †.

Mr. Monnier selected zinc as an auxiliary metal, in the proportion of 4 to 8 per cent. The alloy is only a real one in the proportion of 1 per cent.; the surplus being merely a mixture. This mixture, effected at a high temperature, is an imperfect one, owing to the difference of density of the two metals; it is, however, obtained by means of certain tricks of the trade.

The electrodes are plates 3 mm. thick. The zinc, being eliminated by repeated immersions in caustic lixiviations and sulphuric acidulated water, leaves a numerous series of small holes which render the lead porous, permeable in the whole of its thickness to electrolytic actions. This mode of preparing the electrodes is not without some analogy with the deep scourings obtained by Mr. Planté with nitric acid.

The elimination of the zinc must be completed by the formation. Under the action of the electric current, the direction of which is several

* The author of this book, also, was not acquainted with these anteriorities when he described the Monnier accumulator before the 'Société des Ingénieurs Civils' (4th July, 1884), and in "Le Génie Civil' (9th August, 1884).

† Denis Monnier, Professor to the Geneva School of Chemistry; French patent No. 152,607, 13th December, 1882, 'Perfectionnements aux accumulateurs d'électricité."

times reversed, the two electrodes, each positive by turn, liberate the last traces of zinc, in a state of sulphate of zinc, which dissolve in the liquid. The sulphuric acidulated water must be frequently renewed, otherwise the remaining zinc would be indefinitely vehiculated from one electrode to the other, and the formation could not be completed.

The repeated scourings, the numerous lixiviations, and the necessary reversals with frequent renewals of the liquid, make the formation of the plates tedious and costly; but the result is well worth the trouble and expense.

Monnier's electrodes have an elevated voltaic capacity, are compact, homogeneous and durable. The stiffness of the electrodes allows of a simple and strong mounting, as illustrated in the

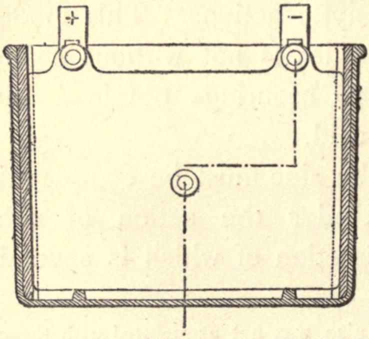


FIG. 26.

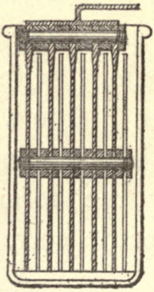


FIG. 27.

longitudinal section, Fig. 26, and in the transversal one, Fig. 27.

The accumulator is composed of an even

number of similar plates alternately positive and negative, and placed very near each other. Each plate is provided with a boss coming outside the liquid; the bosses on the positive plates are all on one side, and those on the negative plates on the opposite side of the accumulator. The positive and negative electrodes are all joined together respectively, by means of a rod of ebonite passing through the holes in the bosses, and they are maintained apart by means of the interposition of isolating washers. This compact ensemble is supported by two transversal bars, and is maintained, at each end, by means of two grooved wooden panels, the grooves of which receive the edges of the vertical plates.

The jar is made of sandstone.

The following data refer to a ten-plate accumulator:

Total surface of the ten plates	110 square decimeters.
Weight of each plate	1900 grammes
„ of the ten plates ..	19 kilogrammes
„ of the liquid (acidulated water $\frac{1}{10}$) ..	4 „
„ of the jar	4 „
Total weight	29 „
Voltaic capacity	144 ampère-hours
Intensity of the normal discharging current	23 ampères
Intensity of the charging current	13 „

The voltaic capacity is 7·6 ampère hours per kilogramme of plate.

The Monnier accumulator is not in industrial use ; but there is no reason for this, as it is a good apparatus.

Sulphuretted Electrode Accumulators.—The sulphuretting of lead electrodes, previous to the formation, quickens the latter. This process is attributed to Mr. Schulze.

The plates are sulphuretted to a certain depth by means of an addition of brimstone heated in contact with them. They are formed by the Planté process. The sulphur, carried away with the gases of the electrolysis in a state of sulphuretted hydrogen and sulphurous acid, leaves some porous lead at the surface of the electrodes.

No data exist as regards accumulators thus formed.

CHAPTER V.

ACCUMULATORS OF THE PLANTÉ TYPE. HETEROGENEOUS FORMATION.

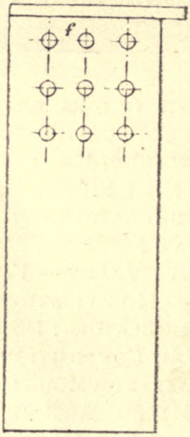
ACCUMULATORS WITH OXIDES OR INSOLUBLE LEAD SALTS JUXTAPOSED TO CONDUCTIVE SUPPORTS: CAMILLE FAURE SYSTEM — ACCUMULATORS WITH RETICULATED ELECTRODES FILLED WITH FINELY DIVIDED LEAD: VOLCKMAR SYSTEM — ACCUMULATORS WITH SOCKETTED OXIDES: FAURE-VOLCKMAR SYSTEM—SELLON'S GRATINGS OF LEAD AND ANTIMONY ALLOY — FAURE - SELLON - VOLCKMAR ACCUMULATOR — MODIFICATION TO FAURE - SELLON - VOLCKMAR ACCUMULATORS: DOUBLE ELECTRODES—MODIFICATIONS IN THE COMPOSITION OF THE LIQUID, BY MR. CHARLES PHILLIPART—MOUNTING IN COLUMNS, BY G. PHILIPPART — MIXED ACCUMULATOR: FAURE - REYNIER SYSTEM—JUXTAPOSED AMALGAMS: NÉZERAUX ACCUMULATORS — AGGLOMERATE OXIDE OF LEAD ELECTRODES: ARON'S METALLOIDIUMS AND METALLOIDIONS; TRIBE PEROXIDE OF LEAD ELECTRODES; FRANKLAND AGGLOMERATED ELECTRODES; R. TAMINE AGGLOMERATED ELECTRODE ACCUMULATORS; FITZGERALD LITHANODE—ELECTRO-CHEMICAL FORMATION: MONTAUD ACCUMULATOR.

Accumulators with Oxides or Insoluble Lead Salts juxtaposed to Conductive Supports—Camille Faure System.—Well-formed Planté's electrodes are composed of a metallic lead core, covered with a permeable layer the active portion of which is peroxide on the positive and reduced lead on the negative.

In Planté's process of formation, these permeable materials are produced from the electrode's lead itself (autogeneous formation).

Mr. Camille Faure* has obtained at once some electrodes with thick layers of active

FIG. 28.



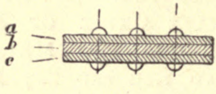


FIG. 29.

materials, by coating some lead plates with pastes of sulphate of lead, or of oxides of lead backed by felt partitioning (Figs. 28 and 29).

Electrodes thus prepared can be formed with a

* French patent No. 139,258, 20th October, 1880, "Perfectionnements aux batteries galvaniques et applications de ces batteries aux locomotives électriques"; French patent No. 141,057, 9th February, 1881, "Perfectionnements dans les dispositions et la construction des couples-batteries secondaires."

single charge of 150 hours. The formation converts the pulverulent masses into solid, porous and conductive crusts of reduced lead, and of peroxide of lead more or less mixed with sulphate of lead.

The Faure accumulators, like those of Planté,

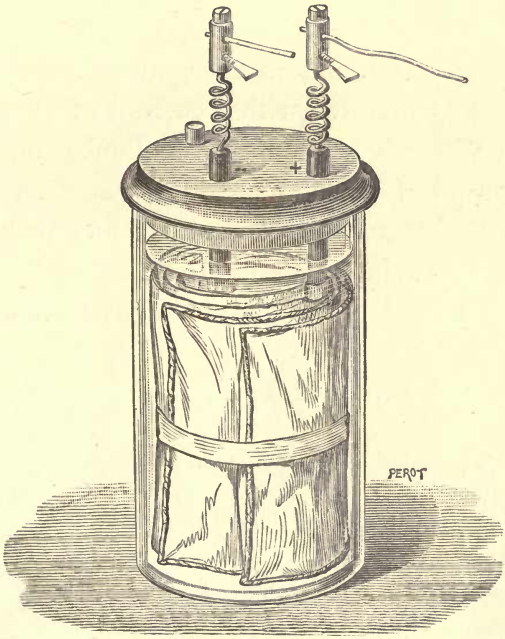


FIG. 30.

are composed of a greater or smaller number of alternating plane electrodes, or of a single pair of spiral wound electrodes (Fig. 30).

A committee of the jury of the Paris Exhibition

of Electricity (January 1882), has carried out a series of experiments upon the Faure accumulators, the results of which have been communicated to the Académie des Sciences.*

The battery experimented upon consisted of 35 round couples weighing each an average of 43·7 kilogrammes; the electrodes, coated with a layer of 10 kilogrammes of oxide of lead per square meter, weighed about 30 kilogrammes.

The 35 accumulators charged in series during 22 hours 45 minutes, with a current of 11 to 6·36 ampères, received 694,500 coulombs under an average fall of 91 volts.

The discharge, which lasted 10 hours 39 minutes, with a mean intensity of 16·2 ampères, and a mean potential of 61·5 volts, gave off 619,600 coulombs.

We deduce from these data:

Average potential of the charge for 1 accumulator	2·6 volts.
Fall of potential utilised during the discharge	1·76 ,,
Voltaic capacity per kilogramme of accumulator	14,000 coulombs.
Voltaic capacity per kilogramme of electrodes	20,653 ,,
Proportion between the quantities given off and received	0·89 ,,

* Note of Messrs. Allard, Joubert, Potier, and Tresca, presented at the meeting of the 6th March, 1882.

Proportion between the potentials of discharge and charge	0·675 ,,
Electrical efficiency of the battery	$0{\cdot}89 \times 0{\cdot}675 = 0{\cdot}60$
Available energy per kilogramme of accumulator	2,500 kilogrammètres.
Weight of accumulator necessary for the production of one electrical horse-power per hour	108 ,,

The immediate results obtained with the Faure system have deeply impressed the electricians; they, for the first time, gave an exact idea of what services could be expected from secondary couples, which until then had scarcely been appreciated outside the laboratory where the couples in use had been laboriously formed.

The defects of Faure accumulators made themselves apparent, at the same time as its qualities, and the principal of those were the short duration of the felts, the disaggregation and fall of the permeable crusts which the increase infallibly separated from their supports.

This mode of supporting the active materials by means of felt partitions had to be abandoned. But the principle of heterogeneous formation, by additions of oxides, remains in force, and is the basis of the system of accumulators actually the most in use industrially, the Faure-Sellar-Volckmar system, which will be hereafter described.

Accumulators with Reticulated Electrodes, filled with finely divided Lead: Volckmar System.—Mr. G. Philippart endeavoured to avoid the inconvenience of the partitioning, without doing away with the advantages of the heterogeneous formation. He succeeded in this, by making use of thick plates, perforated with holes, cells, or reticules containing the active materials. This ingenious device has been patented by Mr. E. Volckmar.*

The first plates manufactured by Mr. G. Philippart, were made with sheets of laminated lead 3 or 4 mm. thick, and mechanically perforated; the cells, which were numerous and very close to each other, were garnished with very finely divided lead, in the shape of foils, threads, or, even better, in a state of chemical precipitate or frothy lead.†

Lead foils or threads take a long time to form, whereas the forming of frothy lead is comparatively quick; the plates garnished with it acquired, after 150 to 200 hours' charging, a large voltaic capacity.

Frothy lead is obtained by precipitating the lead, with zinc, from its nitrous or acetic solution. The material thus obtained is very costly, and its use is less convenient than that of the lead oxides.

* French patent No. 145,218, 8th October, 1881, "Nouveau système de piles secondaires."

† The use of frothy lead in accumulators was mentioned in Mr. Tommasi's, French patent No. 143,555, 3rd September, 1881.

Accumulators with Socketted Oxides: Faure-Volckmar Systems.—The defects of each of the two primitive systems have been done away with by garnishing Volckmar's cells with Faure paste.

The reticulated plates which support the active materials are lead gratings, as light as possible, cast in moulds (Fig. 31). The taper necessary

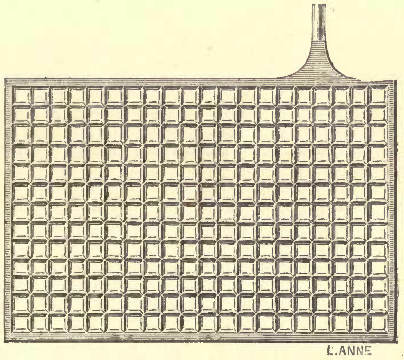


FIG. 31.

for unmoulding is taken by halves on each side of the plate, so that the shape of the cell is that of two truncated pyramids joined at their small basis, the large basis being level with the external planes of the plate.

The blocks of active materials socketted into these tapering cells, are held in their middle, and, so to speak, riveted in the supporting grate.

The garnished plate (Fig. 32) brings the active materials in contact with the liquid on the near totality of its surfaces; for the edges of the

gratings, reduced to a minimum, and coming flush with the surfaces of the plate, only show as straight lines on the said surfaces.

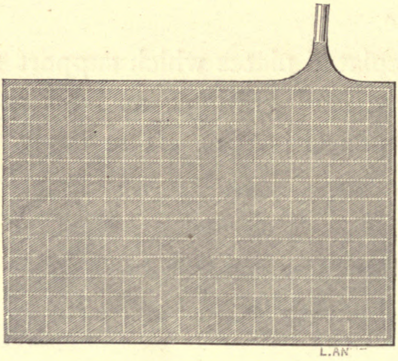


FIG. 32.

The pastes for garnishing the cells are made of oxides of lead, firmly gauged in sulphuric acidulated water. Peroxide of lead is used for the positive and protoxide of lead for the negative plate. The gauging produces a small quantity of sulphate of lead in a supersaturated solution; when drying, the sulphate slowly becomes solidified into the mass and hardens. The setting of the paste takes place in the same manner, and owing to analogous chemico-physical phenomena, as that of mortar.

The forming does not produce any apparent increase, for the density of the pastes is such that their conversion into peroxide and reduced lead, takes place without expansion or contraction.

This happy result, which the inventors obtained without seeking for it,* secured the success of the heterogeneous formation in the Faure-Volckmar accumulators.

As regards the increases by discharge, they are in this instance subdivided into numerous parts; the expansions produced in each cell do not exceed the plastic faculties of the active materials.

In fact, the negative electrodes have a very long life (some say indefinite).

The positive electrodes, on the contrary, perish after a short time, owing to a destructive formation of the grating, the metal of which becomes more and more peroxidised. The support thus attacked increases, expands up to rupture, warps, and sometimes comes into contact with the negative plates, and ultimately drops the active materials which it contained. These accidents are the cause of frequent repairs and renewals of the positive plates.

Sellon's Gratings of Lead and Antimony Alloy.—The destruction of the positive gratings is considerably delayed by making them of lead and antimony.†

* The study of increase is subsequent to the Faure-Volckmar invention.

† J. S. Sellon, English patent 3987, 1881, "Secondary batteries or magazines of electricity." French patent 147,831, 10th March, 1882. 'Perfectionnements aux piles secondaires ou accumulateurs d'électricité.'

This alloy is harder than lead, and possesses, when cooling, a property of expansion, owing to which the castings are of great neatness. For these reasons, antimony, which is indispensable with positive gratings, is also introduced, although in reduced proportion, into the negative ones, the stiffness of which is increased thereby.

Faure - Sellon - Volckmar Accumulators.—The lead and antimony alloy used by Mr. Sellon in the construction of the Faure-Volckmar accumulators has, in a certain measure, given these apparatus the strength and duration they were deficient in. The couples thus perfected are designated "Faure-Sellon-Volckmar accumulators."

They are made of numerous patterns, differing in sizes, thicknesses, and number of plates. Fig. 33 illustrates a specimen of French manufacture set up in a wooden jar internally lined with lead. Fig. 34 illustrates one of its electrodes, an elevation and vertical section of which are shown in Figs. 35 and 36 respectively.

The specimen illustrated in Fig. 33 is one comparatively heavy, intended for lighting stations: some lighter types are constructed for tramway traction. The data relating to two patterns especially selected respectively amongst the lighting and traction types, are given in the two following tables.

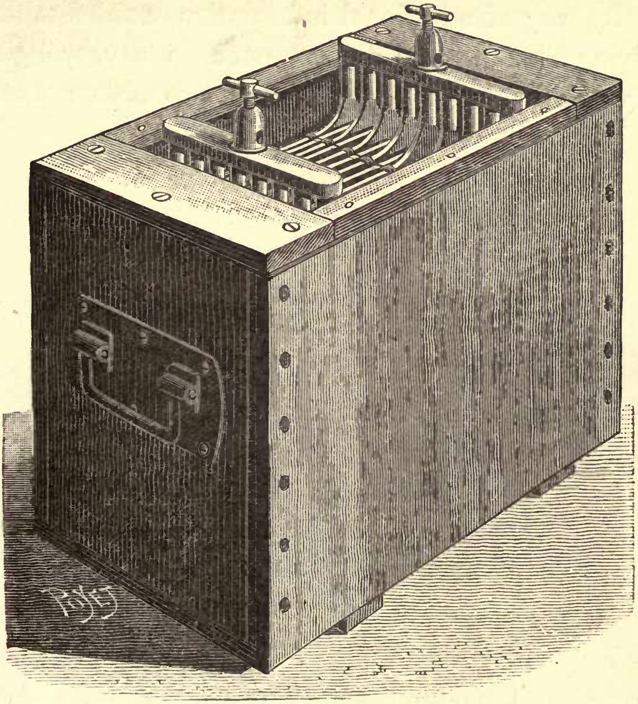


FIG 33

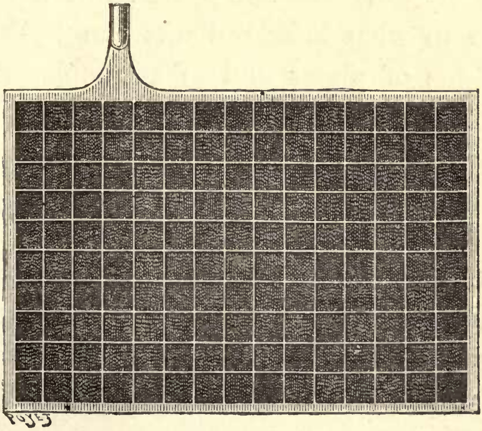


FIG. 34.

By way of additional information, a third table, giving similar data in reference to a very light couple, has been added to the two above men-

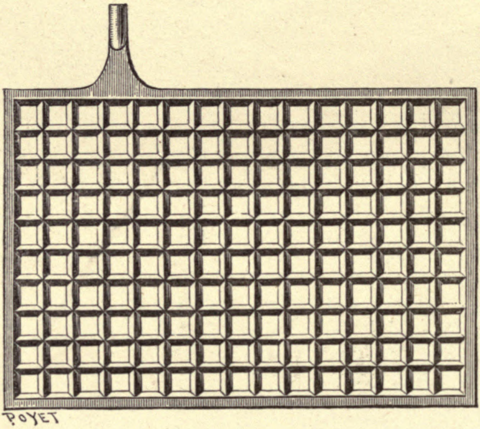


FIG. 35.

FIG. 36.

tioned. This unique apparatus has been constructed by Mr. G. Philippart with a view to ascertain to what inferior limits can be brought the weights of plates and of accumulators compared to the energy and the work. The gratings are only 2 mm. thick; they are reticulated so as to hold a weight of materials equal to their own weight.

The delicate and expensive plates give some surprising results; but their manufacture and use would require an amount of attention out of proportion with the existing uncertainty of the industrial practice.

FAURE-SELLON-VOLCKMAR ACCUMULATOR.

Stationary Pattern for Lighting Station.

Wooden and Lead Jar. (*Fig.* 33).

Sizes of plates	Length ..	310 millimetres.
	Height ..	215 „
	Thickness ..	005 „
Number of positive plates ..		8
„ negative „		9
Useful surface of the 17 plates		208 sq. decimetres.
Weight of each plate		2·350 kilogrammes.
„ the 17 plates		40 „
External sizes of the accumulator	Length	400 millimetres.
	Width	200 „
	Height	380 „
Weight of the complete accumulator full of liquid		60 kilogrammes.
Intensity of the charging current		40 ampères.
„ „ discharging „		60 „
Voltaic capacity		400 ampère-hours.
Useful normal energy		108 watts.
Utilisable total work		0·97 H.-P. per hour.
Regimen of discharge per sq. dec. of plates		0·29 ampère.
Regimen of discharge per kilogramme of plates		1·5 „
Voltaic capacity per kilogramme of plates		10 ampère-hours.
Voltaic capacity per kilogramme of permeable material		30 „
Weight of accumulator corresponding to 1 H.-P. energy .		408 kilogrammes.
Weight of plates corresponding to 1 H.-P. energy		272 „
Weight of accumulators corresponding to 1 H.-P. electrical work		62 „
Weight of plates corresponding to 1 H.-P. electrical work ..		41 „

FAURE-SELLON-VOLCKMAR ACCUMULATOR.

Portable Pattern for Tramway Traction.

Ebonite Jar.

Sizes of plates	Length	150 millimetres.
	Height	150 ,,
	Thickness ..	004 ,,
Number of plates, positive ..		8
,, ,, negative ..		9
Useful surface of the 17 plates		72 square decimetres.
Weight of each plate		0·600 kilogramme.
,, the 17 plates		10·2 ,,
External sizes of the accumulator	Length	170 millimetres.
	Width	130 ,,
	Height	230 ,,
Weight of the complete accumulator, full of liquid		13 kilogrammes.
Intensity of the charging current		10 ampères.
Intensity of the discharging current		20 ,,
Voltaic capacity		120 ampère hours.
Useful normal energy . ..		36 watts.
Utilisable total work		0·3 H.-P. per hour.
Regimen of discharge per square decimetre of plates		0·28 ampère.
Regimen of discharge per kilogramme of plates		2 ampères.
Voltaic capacity per kilogramme of plates		12 ampère hours.
Voltaic capacity per kilogramme of permeable material		36 ,,
Weight of accumulator corresponding to 1 H.-P. energy		260 kilogrammes.
Weight of plates, corresponding to 1 H.-P. energy		204 ,,
Weight of accumulators corresponding to 1 H.-P. electrical work		43 ,,
Weight of plates corresponding to 1 H.P. electrical work ..		34 ,,

FAURE-SELLON-VOLCKMAR ACCUMULATOR.

Experimental Pattern with Thin Plates.

Ebonite Jar.

Sizes of plates: Length	150 millimetres.
Sizes of plates: Height	150 „
Sizes of plates: Thickness ..	002 „
Number of plates, positive ..	12
„ „ negative ..	13
Useful surface of the 25 plates	108 square decimetres.
Weight of each plate	0·245 kilogramme.
„ the 25 plates	6·125 „
External sizes of the accumulator. .. Length	170 millimetres.
External sizes of the accumulator. .. Width	130 „
External sizes of the accumulator. .. Height	230 „
Weight of the complete accumulator full of liquid	9·700 kilogrammes.
Normal intensity of the charging current	10 ampères.
Normal intensity of the discharging current	20 „
Voltaic capacity	155 ampère hours.
Useful normal energy	36 watts.
Utilisable total work	0·36 H.-P. per hour.
Regimen of discharge per square decimetre of plates	0·186 ampère.
Regimen of discharge per kilogramme of plates	3·25 „
Voltaic capacity per kilogramme of plates	25 ampère hours.
Voltaic capacity per kilogramme of permeable material	50 „
Weight of accumulator corresponding to 1 H.-P.	200 kilogrammes.
Weight of plates corresponding to 1 H.-P.	125 „
Weight of plates corresponding to 1 H.-P. electrical work ..	25·500 „
Weight of plates corresponding to 1 H.-P. electrical work ..	16·120 „

The English manufacture of Faure-Sellon-Volckmar accumulators, monopolised by the Electric Power Storage Company, offers a great variety of types, Fig. 37 being an illustration of one.

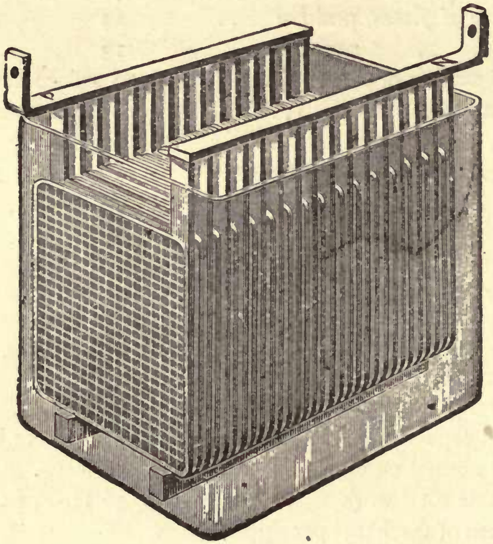


FIG. 37.

The glass jars used by this Electric Power Storage Company, more particularly for stationary purposes are, it appears, stronger than would be supposed; they very seldom break, afford a good isolation and great facilities for the inspection of the couples. They make the positive plates slightly thicker than the negative, With the exception of detail of construction, and the particular setting up of certain patterns, the English

manufacture does not differ much from the French, and gives equivalent results.

The Faure-Sellon-Volckmar accumulators manufactured in Belgium, Austria, and America, are not possessed of any particular feature worth noticing.

Modifications to Faure-Sellon-Volckmar Accumulators.—Amongst the numerous improvements which the Faure-Sellon-Volckmar accumulators have been subjected to, several of them deserve noticing.

Double Electrodes.—At the origin of the industrial exploitation of accumulators, it often happened that the active materials got detached from their supports, and this more particularly in the case of positive plates. These accidents were due to a defective manufacture, and to faults committed in the management and use of the batteries. It was thought that the fall of the cakes of active materials could be prevented by shutting them into taper cells, the small diameters of which were situate externally. Gratings were, to that effect, cast with only one tapering, and two of them, riveted together, constituted one electrode. The tapers of the two plates thus joined were opposite each other, and turned toward the interior of the plate, so as to form cells swollen in their middle.

Figs. 38 and 39 are illustrations of a double plate, being a vertical section and an elevation respectively

FIG. 38.

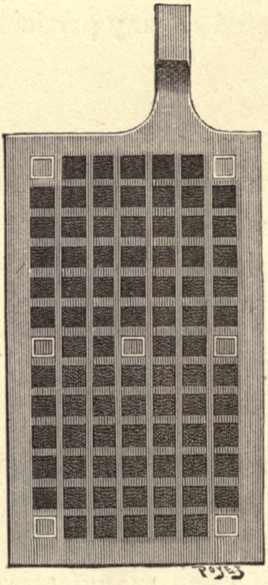


FIG. 39.

The manufacture of these plates is complicated; their dead weight is greater than those of single plates; the active materials which they contain are only accessible to the liquid through some reduced surfaces; whence diminution of the voltaic capacity, increase of the internal resistance and lowering of the charging and discharging regimens.

These serious defects are not compensated by

an improved behaviour of the active materials, the fall of which appears, on the contrary, to be accelerated.

An important trial of the double plates took place in 1883 and 1884 with a large battery of accumulators erected at the Hôtel des Postes; the results were bad.

Modifications in the Composition of the Liquid, by Mr. Charles Philippart.—Certain applications, such as to carriage traction and boat propulsion, require the use of very large electrical power combined with a restricted total weight; the normal output of ordinary accumulators then becomes insufficient. It should be increased without reducing the thickness of the plates, the strength of which must be preserved.

Mr. C. Philippart has succeeded in this direction by adding some oxygenated water in the liquid of the couples.* The result was an increase of the output regimen which could be brought to 4 ampères per kilogramme of ordinary plates. The fall of external potential, besides, increased from 0·1 to 0·2 volt, and there was a notable increase in the voltaic capacity.

Mr. C. Philippart, at first, depended on the oxidising action of the binoxide of hydrogen, but soon perceived that the results obtained must

* French patent, No. 159,933, 25th January, 1884. 'Nouveau système pour dèpolariser les piles secondaires.'—Charles Philippart.

be attributable to some other reasons. In effect, the liquid keeps its properties for a long time, and is capable of supplying numerous intense discharges, without a renewal of oxygenated water; this negatives the aforesaid theory—electrolytic deoxidisation. The inventor now attributes the increased energetic action of the liquid to a sulphate (or polysulphate ?) of binoxide of hydrogen. This sulphate of binoxide would liberate some sulphuric acid in a particular state and possessed of greater affinities than that coming out of the sulphate of protoxide. The liberated binoxide of hydrogen would be resulphated at the same rate that it gets desulphated, thus remaining fit to electrically carry an indefinite quantity of sulphuric acid.

Some recent experiments seem to confirm this theory. Mr. C. Philippart has observed that the addition, in sulphuric acidulated water, of certain non-oxidising sulphates give the same results as that of oxygenated water. Sulphate of ammonia, notably, gives some remarkable results.

The amplified discharges obtained with the new liquids necessarily cause an augmentation in the increase by discharge, with the consequent tendency to push the active materials out of their cells. In order to render the plates fit to receive, without degradation, some greater expansions, their construction should be altered. This question is now being studied.

Mounted in Column by Mr. G. Philippart.—A secondary battery of some importance contains several hundred parts, such as jars, electrodes, isolating pieces, collectors, junctions, &c., the whole being costly, cumbrous, difficult of removal and handling.

At the beginning of his researches, Mr. Faure attempted to simplify secondary batteries by constructing some accumulators with parallel electrodes similar to ordinary trough voltaic batteries.*

This idea has also been worked out by several other inventors, but none have succeeded in obtaining the perfect watertightness of the trough compartments and isolation of the juxtaposed couples.

Mr. G. Philippart gives to multiple accumulators a form which is more easy of practical realisation.† In this system, the electrodes are double; they are conical or truncated, positive on one face and negative on the other. These cones are piled up vertically, one inside the other, with interposition of isolating material. The liquid is introduced in the watertight compartments formed by every two successive cones, and there are as many couples, minus one, as there are cones.

* French patent, No. 139,258, 20th October, 1880.

† French patent, No. 157,139, 21st August, 1883. 'Construction nouvelle des accumulateurs électriques.' G. Philippart.

The cones are made of a cast core of lead and antimony, covered on its two faces with a paste of oxides of lead. Some grooves, cast with the cores, constitute the cells which hold the active materials.

In order to render this system practical, the cast cores with cells should be of large dimensions, not too heavy and perfectly sound; the difficulties of obtaining these results do not seem insuperable.

Mixed Accumulator: Faure-Reynier System.—Before closing the chapter of oxide accumulators, we will describe this combination of a Faure negative with an autogeneously formed plaited positive.

This system was established by the author of this book in the workshops of the Geneva Society of Mechanical Construction.

The jar of this accumulator (Fig. 40) is made

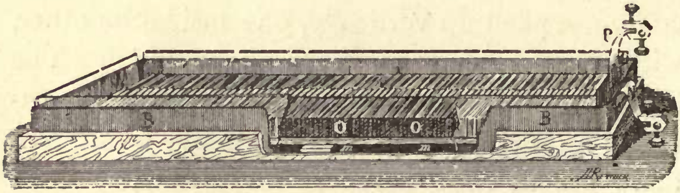


FIG. 40.

of a leaden sheet, the borders of which are uplifted but not soldered, externally supported by

a long rectangular wooden trough. This leaden box, the bottom of which is covered with peroxide of lead *m m*, constitutes the negative electrode of the accumulator. A strip of lead N, externally soldered to it, serves as a connecting piece.

The positive electrode (Fig. 42) is made of a long leaden strip, plaited, and slit along all the folds so as to offer the whole of its surfaces to the electrolytic action. In order to prevent this electrode being cut in any portion of its length by a deep formation, it has been strengthened in its

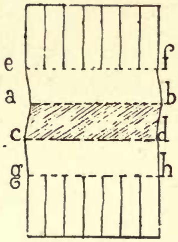


FIG. 41.

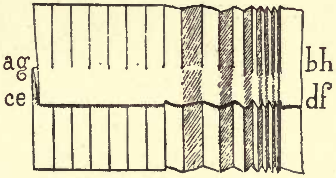


FIG. 42.

middle part, by means of two superposed folds (Fig. 41), *e f* which folds upon *c d*, and *g h* which folds upon *a b*. After this double folding lengthwise, the strip is plaited crosswise; then all the folds are slit from the border to the medium edge. One of the ends of the electrode emerges from the liquid, and to it is attached a strip of soft lead for connection purposes; P is a binding screw.

The two electrodes are separated from each

other at the sides by means of lateral glass strips V, V, V, and at the bottom by means of longitudinal and transverse sleepers.

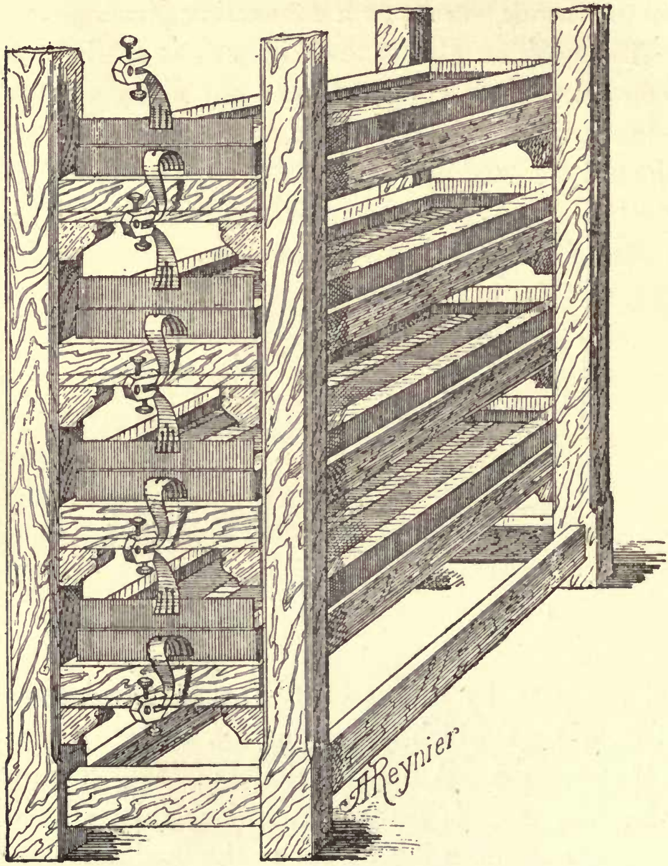


FIG. 43.

The accumulators are placed in a rack (Fig. 43) and connected in the usual manner.

This pattern is an economical one to manufacture and use: lead, peroxide of lead, wood, and sulphuric acid are the only materials used in its composition; it requires very little attention, and the renewals are as cheap of cost as easy to effect.

Sixty of these couples have been in use during several months, for the lighting of the "Bouffes," Geneva.*

Juxtaposed Amalgam: Nézeraux Accumulators.†—The active portion of Nézeraux's plates is a mass of spongy lead obtained by the elimination of the mercury in an alloy of mercury and lead. This amalgam contains one part of mercury, to two parts of lead; it is obtained by fusion in an iron pan. It is left to crystallise by cooling, and then reduced to a fine powder.

The core of the electrode is a grating set in a projecting frame. The pulverulent amalgam is applied on both faces of the grating until it reaches an even level with it, and then agglomerated by pressure. Immersion in sulphuric acidulated water, and exposure to atmospheric air knead the mass and give it cohesion.

The plates thus prepared are submitted to the forming current which peroxidises the positive and

* March 1883.

† 'La Lumière Électrique,' 23rd and 30th May, 1885.

eliminates their mercury. The current being reversed, the negative become positive and get, in turn, peroxidised; whereas the ex-positive become negative and pass into a state of very permeable reduced lead. The eliminated mercury is gathered at the bottom of the forming jars.

According to the inventor, plates thus formed are possessed of a very great strength and long duration. They could give up to 25 ampère hours per kilogramme, this high capacity resulting from the large proportion of permeable materials which represent the three-quarters of the weights of the plates. The charging and discharging regimens may vary from ½ to 3 ampères per kilogramme, and the electromotive force of the couples is a little higher than that of other systems of the Planté type.

These accumulators have never been used industrially, and one has to rely on the inventor for the data. *A priori*, the juxtaposed amalgam plates seem to be costly, owing to the losses of mercury. The manipulation of this metal in large quantity would prove more injurious than that of lead.

Agglomerate Oxides of Lead Electrodes.—In the Faure system, the first industrial attempt at heterogeneous formation, the active materials, of feeble cohesion and feebler adherence, are held against their support by means of per-

meable partitions. The reticulated plates, which constitute an important progress, hold the materials without the help of any partition; their defect resides in the excessive weight of the grating, which amounts to two-thirds of the total weight. The Nézeraux plates show a tendency to reduce the dead weight by giving predominance to the weight of the permeable mass.

The object, in the following systems, has been to still more reduce the weight of the conducting support in favour of the active materials; agglomerating the latter to give them cohesion, and a better internal conductivity.

*Aron's Metallodiums and Metallodions.**—Dr. H. Aron, of Berlin, has given the name of metallodions to metallic oxides agglomerated with collodion upon lead or carbon conducting supports. Peroxides of lead and of manganese may be used as positive electrodes in primary batteries.

He calls metallodiums permeable metallic agglomerated materials, indirectly obtained by the electrolytic reduction of the metallodions, or directly by the agglomeration of very finely divided metals.

Metallodions of peroxide of lead and of reduced

* Belgian patent, 30th June, 1882, mentioned in Mr. Tribe's work.

lead have been proposed as positive and negative electrodes for electric accumulators.

*Tribe Peroxide of Lead Electrodes.**—The inventor has indicated the use of peroxide of lead in the state of compressed masses, or natural and contained in isolating porous jars. He has not described the mode of attaching.

Frankland Agglomerated Electrodes.†—The active material of these plates is a hardening mixture composed of an oxide of lead other than the peroxide; of dilute sulphuric acid, and of an acid solution (phosphoric, chlorhydric, oxalic, &c.) suitable to the formation of insoluble or little soluble lead salts. These mixtures, applied on conducting supports, set and harden rapidly.

R. Tamine Agglomerate Electrode Accumulators.—Tamine plates are obtained by the following process: "A certain quantity of rosin or other agglomerating material cements, under the enormous pressure of about 300 atmospheres, a mixture of peroxide of lead electrolytically obtained and of lead filings, or of lead pieces, blade, thread, strip, &c., shaped. The object of

* Belgian patent, 28th February, 1883, mentioned by Tamine.

† Belgian patent, 15th March, 1883, mentioned by Tamine.

the latter is to obtain a good distribution of the current in the interior of the electrode." *

In practice, the inventor substitutes minium for the positive and litharge for the negative electrodes to peroxide of lead. The respective proportions are:

POSITIVE ELECTRODE.

Rosin	5 parts.
Conductive metal	75 "
Minium	20 "

NEGATIVE ELECTRODE.

Rosin	3 parts.
Conductive metal	45 "
Litharge	12 "

The positive agglomerate can be used with copper or zinc accumulators; the negative electrodes are then copper, zinc, or carbon plates.

Mr. Tamine does not give the voltaic capacity of his agglomerate electrodes. It cannot but be small, owing to the feeble proportion of active materials indicated in his formulæ.

Fitzgerald Lithanode. †—The lithanode is a cohesive and conductive agglomerate composed

* 'Recherches théoriques et pratiques sur les accumulateurs électriques,' par René Tamine, Mons, 1885.

† D. G. Fitzgerald, English patent 4671, 1885. 'Improvements in the manufacture of elements for voltaic batteries.'

of lead oxides mixed with a solution of ammonium sulphate and powerfully compressed; ammonia is liberated and the sulphate of lead cements the mass. The compression gives the plates a sufficient cohesion to enable them to stand without a metallic support. They are provided with a thin laminated platinum conductor.

The density of lithanode is from 7·5 to 7·9; its voltaic capacity is from 20 to 25 ampère-hours per kilogramme. The plates are about 6 mm. thick, and are mounted with celluloid isolating supports in jars of the same material.

Lithanode, which is a good material for positive plates, does not appear to be so suitable for negative plates. The Fitzgerald accumulators which have been tested were a combination of lithanode positive with Faure-Sellon-Volckmar negative.

These couples are remarkably light: the total weight corresponding to 1 horse-power electrical work being only 31·5 kilogrammes.

Electro-chemical Formation.—The methods used in the formation of accumulator electrodes are mostly chemical or electrical; however, the special qualification of electro-chemical shall be reserved for the process consisting in the offhand formation of the two electrodes by means of a double electrolytic deposition of peroxide of

lead and reduced lead borrowed from or vehiculated by the liquid.

As far back as 1872 Mr. G. Planté* explained the principle of electro-chemical formation in a paper on the use of secondary currents for accumulating or transforming the effects of the voltaic battery. He expresses himself as follows:—

"It is, after all, a galvanic deposit of peroxide of lead which it is proposed to obtain in these secondary couples, deposit which should be as thick as possible in order to accumulate, in that shape, the work of the battery, and, at the same time, sufficiently adhering to the surface of the plate to go through, without becoming detached, an indefinite series of successive reductions and reoxidisations.

"This consideration led me to try to obtain the peroxide of lead on the plates at the expense of the liquid, in order to be able to produce a thicker coating and, to that effect, to use a liquid composed of a more or less dilute solution of a lead salt. But then water acidulated with sulphuric

* Mr. G. Planté was the first to use the expressions accumulator, accumulation, storage of the voltaic energy, which have been, of late, so frequently used. He assimilated his secondary couples to apparatus which, in mechanics, serve for the accumulation of work, such as hydraulic accumulators, springs, &c.; he has determined one of the factors of their efficiency, and observes that "a well-formed secondary couple with lead plates constitutes a real accumulator of the work of the voltaic battery." (Recherches sur l'Électricité,' 1879, paragraphs 89, 91, and 92.)

acid cannot be used any more, this acid precipitating the salt of lead ; and, if other acid solutions containing that metal be used, the lead deposits on the negative plate in the shape of crystalline needles which very soon establish some contacts with the positive plate, and thus stop any ulterior decomposition.

"Should alkaline solution be used, lead deposits in a spongy shape, rapidly increasing in volume*, give rise to the same inconveniences as before ; moreover, the peroxide of lead, once deposited, shows no tendency to be attacked by the alkaline solution, as it is in sulphuric acid, so that, in those conditions, a very feeble secondary current only is obtained. I have therefore, until now, used nothing else but $\frac{1}{10}$ sulphuric—acidulated water which has always produced, by its action upon the peroxide of lead, secondary currents of intensities greater than any other acid or alkaline solutions."†

Electrodes formed in an alkaline solution of lead must be transferred to a sulphuric acidulated

* The galvanic deposition of lead under that form, which we might call "Saturn sponge," offers a curious effect of a kind of mechanical combination of lead and hydrogen. This gas is neither combined nor chemically allied to the metal, for it disappears by simple pressure ; but it contributes in swelling, in a remarkable manner, the volume of the metal, similarly to the ammonia gas in an amalgam of ammonium.

† 'Les Mondes,' 14th and 21st March, 1872, vol. xxviii., pp. 425 to 431, and 469 to 477.

water-bath. This has been done by Mr. Montaud.

Montaud Accumulators.—The electrodes of the Montaud accumulators are made of laminated lead plates which are formed off-hand, by electro-chemical depositions, in a bath of lead and potash heated to about 100° C. The electric current deposits upon the positive plates some compact and adhesive peroxide of lead, and some diffuse spongy lead on the negative.

The positive plates are ready for use after coming out of the bath and being washed in a stream of water. The negative must be submitted to a great pressure, which agglomerates the frothy lead and fixes it to its support. Lead thus agglomerated resembles ordinary metallic lead, but it is permeable.

The formation in the plombite bath is very quick: lasting only 15 to 30 minutes. The intensity of the current must be about 600 ampères for each square meter of electrode to be formed.

The plates are rectangular (Fig. 44), indented at one of the top corners, and double-folded at the other. They are cut two at a time, the indenture of one supplying the necessary material for the fold of the twin one. In the reinforced corner a square hole is punched. The negative plates

alternate with the positive ones, the indentures of the one corresponding with the thick parts of the

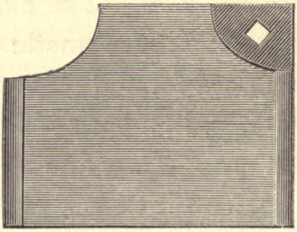


FIG. 44.

other. Two collectors of square section (Fig. 45), made of lead and antimony, are passed through the square holes of the positive and the negative

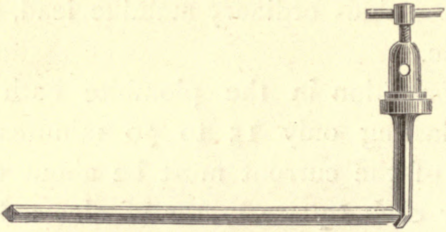


FIG. 45.

plates respectively, and they are fixed to them by autogeneous soldering.

The distance between the plates is maintained by means of wooden vertical combs (Fig. 46); some smaller horizontal combs complete the appa-

ratus, and bring the electrodes into a compact whole. (Fig. 47).

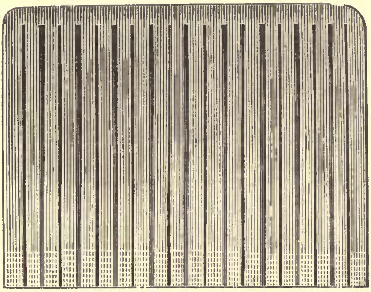


FIG. 46.

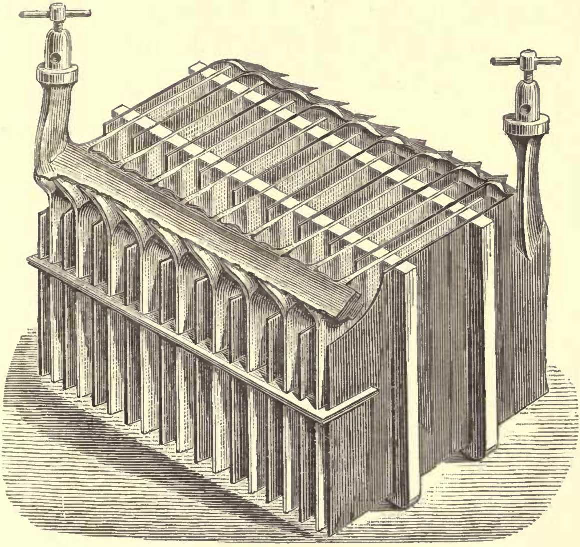


FIG. 47.

The woodcut shows all the plain corners bent upon one another over the collectors and covered

with a conducting strip (all soldered together autogeneously).

The combs round the plates form some wooden girdles which isolate them from the walls of the jar. The latter are made of varnished sandstone, glass, ebonite or wood lined with lead.

According to Mr. Montaud, the following result per square meter of electrodes, is obtained.

Regimen of charge	10 ampères.
„ „ discharge ..	20 „
Utilisable voltaic capacity ..	34 ampère-hours.

With negative electrodes 1 millimetre thick, and positive 2 millimetres, the square meter of electrodes weighs about 9 kilogrammes. The previous data, reduced to the kilogramme of electrodes, therefore become:

Regimen of charge	1·11 ampères.
„ „ discharge ..	2·22 „
Utilisable voltaic capacity	3·77 ampère-hours.

The regimens of charge and discharge are good, but the voltaic capacity is low.

CHAPTER VI.

MISCELLANEOUS ACCUMULATORS.

LEAD-COPPER ACCUMULATORS — LEAD-ZINC ACCUMULATORS D'ARSONYAL AND CARPENTIER ACCUMULATORS; REYNIER ACCUMULATORS; BAILLY ACCUMULATORS; TAMINE SOLUTION—ALKALINE-ZINCATE ACCUMULATORS: DE LALANDE AND CHAPERON RECUPERATIVE BATTERIES; COMMELIN-DESMAZURES-BAILHACHE ACCUMULATORS.

IT has been explained in Chapter II. that the industrial voltametric systems numbered only four, giving rise to as many genii of accumulators, viz.:

1. The lead-sulphuric acid genus, or Planté type.
2. The lead-sulphate of copper genus.
3. The lead-sulphate of zinc: the two latter sometimes being a combination of Planté positive with soluble negative.
4. Copper-alkaline zincate, entirely different from Planté's.

The numerous species of the first genus have been described in Chapters III., IV., and V.

The three last genii, of less importance, are described in the present chapter.

Lead-Copper Accumulators.—The essential properties of this type of accumulators have

been explained in the description of the lead-sulphate of copper voltameter. The utilisable electromotive force of this secondary couple is, as we saw, about 1·26 volt.

To make a lead-copper accumulator it is sufficient to immerse some Planté positive plates in a solution of sulphate of copper in the presence of conductive strips unattackable by this liquid.

The chemical reactions of the charge are:

$$\underset{\text{Positive Electrode.}}{SO_4Pb} + \underset{\text{Liquid.}}{SO_4Cu, Aq} + \underset{\text{Negative Electrode.}}{\quad} = \underset{\text{Positive Electrode.}}{PbO_2} + \underset{\text{Liquid.}}{2SO_3, Aq} + \underset{\text{Negative Electrode.}}{Cu}$$

When discharging, the converse reactions take place, with redissolution of the sulphate of copper produced at the negative electrode.

The first lead-copper accumulator appears to have been proposed by Mr. Sutton, in 1881.* It was made of a copper vessel, filled with a solution of sulphate of copper in the midst of which was suspended a lead electrode.

The copper vessel, which played the part of negative electrode, fatally became attacked and eaten up.

The support to the electrolytic deposit must be insoluble in the liquid, and especially when the said support is used as the containing vessel.

An ordinary Planté accumulator, spiral or parallel strips, becomes a copper accumulator if

* Scientific Notes, 124.

copper is introduced in its liquid. No benefit would result from this transformation, as the loss of electromotive force of the couple resulting from it would exceed 0·5 volt. Besides, the apparatus would soon be out of service, owing to the particles of copper falling to the bottom of the cell, and on the isolating bands, and creating internal contacts.

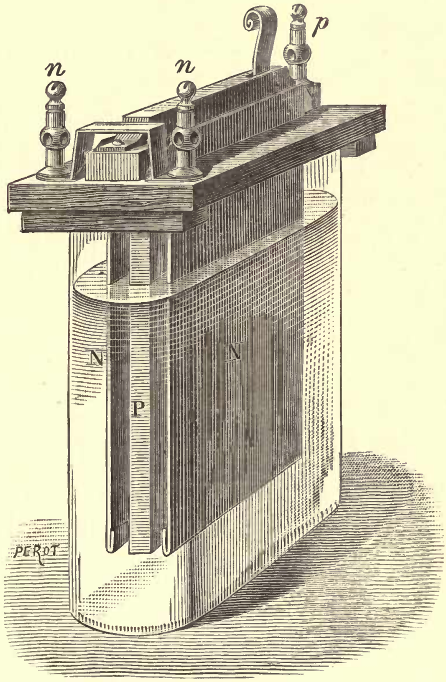


FIG. 48.

The author attempted to avoid this last inconvenience by suspending the electrodes (Fig. 48).

In this accumulator, the positive was a plaited plate similar to that described and illustrated in Fig. 20; it was suspended between two plates of plain laminated lead, in a solution of sulphate of copper. Here, the particles of copper, detached from the cathode, fall to the bottom of the jar. They do not create contacts, but are lost to the action of the liquor, into which they cannot be again dissolved by ultimate discharges, whence the weakening of the solution and a reduction of the voltaic capacity.

It is therefore preferable to adopt the arrangement in which the negative electrodes are horizontal; the copper is thus retained on the cathode, which, becoming the anode during the discharge, restores the lost copper to the voltaic circulation.

That is what the author did at the time of the Nantua experiments, March 1883. One portion of the accumulators used were sulphate of copper, and constructed horizontally and similarly to those illustrated in Figs. 40, 41, 42, 43. To transform this mixed pattern into a copper accumulator, the minium was suppressed and the sulphuric acidulated water replaced by a solution of sulphate of copper. The electrolysed copper fell to the bottom of the leaden jars. These lead-copper accumulators are of an easy and economical construction; they keep the charge satisfactorily. But their electromotive force is low and their voltaic capacity, in function of their weight and

volume, small, owing to the small solubility of sulphate of copper in acidulated water. They are, in fact, less advantageous than accumulators of the Planté type, excepting in the very few cases where a fall of potential lower than 1·25 volt is only utilised.

Lead-Zinc Accumulators.—The essential properties of this system have been described in the voltameter chapter.

It was shown that the reactions of the charge were expressed by the equation

$$\underset{\text{Positive Electrode.}}{SO_4Pb} + \underset{\text{Liquid.}}{SO_4Zn, Aq} + \underset{\text{Negative Electrode.}}{} = \underset{\text{Positive Electrode.}}{PbO_2} + \underset{\text{Liquid.}}{2SO_3, Aq} + \underset{\text{Negative Electrode.}}{Zn.}$$

The utilisable discharge producing the converse reactions.

The electromotive-force of the lead-zinc system is 2·36 volts or one half volt more than that of the Planté system; the electromotive force of the charging current slightly exceeds the utilisable fall of potential, a fact the importance of which will be explained in the following chapter.

Theoretically, the lead-zinc system is the lightest of all known secondary couples. Its construction is economical.

In industrial practice they would, therefore, hold the first rank were it not that they have the grave defect of losing their charge through the

spontaneous dissolution of the zinc in open circuit.

There are several types of lead-zinc accumulators.

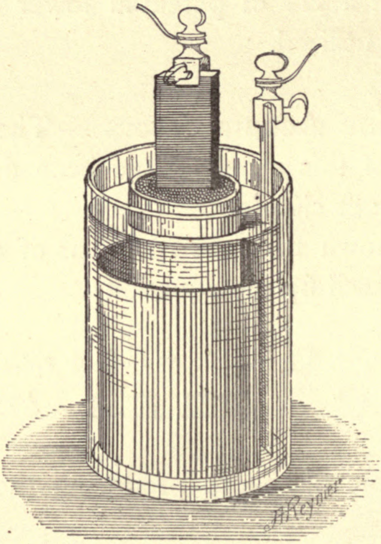


FIG. 49.

*D'Arsonval and Carpentier Accumulators.**—One of the patterns created by Mr. d'Arsonval is

* French patent 133,884, 28th November, 1879; d'Arsonval and Carpentier, 'Couples secondaires à électrodes de métaux différents.' The author mentioned, amongst others, binoxide of manganese as a substitute for peroxide of lead.

In an addition of the 15th March, 1881, they propose to electrolyse the chloride of zinc with two-carbon electrodes; the chloride would be liquefied by its own pressure, and the zinc would be gathered in a basin of mercury.

A second addition, dated 17th August, 1881, mentions the use of bromide and iodide of zinc, the iodine and bromine solutions of which would act as chloride.

illustrated in Fig. 49. This couple has the appearance of an ordinary battery with a porous cell. The zinc is outside. The positive electrode, placed in the centre, is a carbon plate surrounded with very fine lead shot.

The fractioning of the positive and the introduction of a porous cell are the cause of an increased interval resistance; besides, the zinc electrode being without an insoluble support, cannot be of a long duration.

In another pattern, which is not illustrated, the electrolysed zinc was gathered upon mercury.

Reynier Accumulators.—The capital defect of lead-zinc accumulators is, as we have already said, the spontaneous attack of the electrolysed zinc.

The said attack is proportional to the surface of the negative, all other things being equal.

The dissipation of energy will be reduced by relatively reducing the surface of the negative electrodes; this is precisely what has been done in Reynier accumulators by combining plaited positive with plain negative plates. The first accumulators of this system were improvised at Nantua, in February, 1883. Their appearance was most primitive (Fig. 50).

The positive electrode was made of a long sheet of thin lead with reinforced borders, plaited, and slitted, and wound round a wooden form,

I

(Fig. 52); the negative was a plain lead cylinder lining the outer vessel.

A wicker cage (Fig. 51) separated the two electrodes, which rested on a wooden cross at the bottom. The outer vessel was a pine-wood pail,

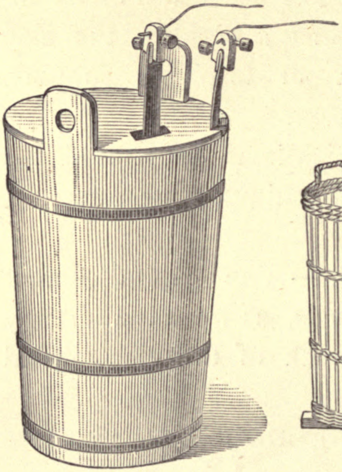


FIG. 50.

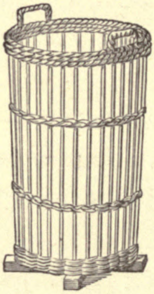


FIG. 51.

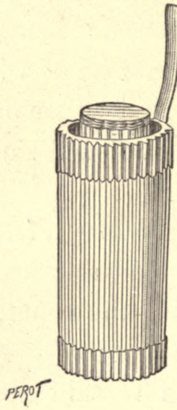


FIG. 52.

tarred internally, and firmly bound together by copper binding.

The active surfaces were 105 square decimeters for the positive electrode and 18 for the negative.

The accumulator weighed, complete, 22 kilogrammes; its voltaic capacity was 300,000 coulombs, its resistance 0·06 ohm., its normal output 15 ampères.

These rough apparatuses answered well in the

experiments for which they had been devised. The pattern was soon discarded, but it deserved mentioning as being the first specimen of zinc accumulator industrially experimented upon. Later on, the inventor suspended his plaited electrodes (Fig. 53), as has already been described

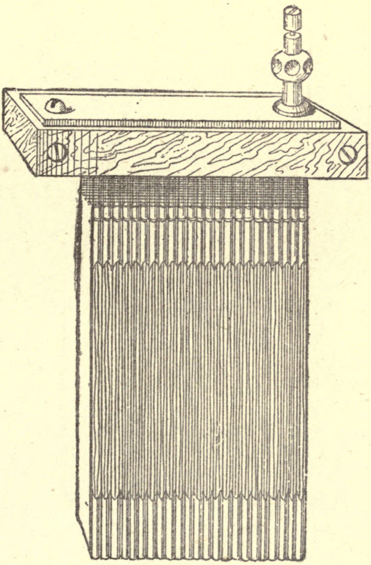


FIG. 53.

in the chapter on Planté's accumulators, with autogenous formation; he has used these plates as positive, in zinc accumulators.

The negative electrodes are protected from a local attack by a well-kept amalgamation. To that effect the lead sheet supporting the zinc

deposit was folded so as to form a kind of pocket (Fig. 54) containing a solid piece of zinc and mercury amalgam, as rich as possible in mercury.

The accumulators were composed of a larger

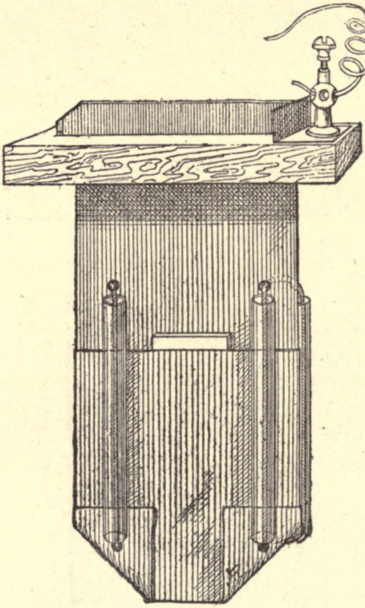


FIG. 54.

or smaller number of plaited positive electrodes alternating with the pocket negative, from which they were isolated by means of vertical glass tubes (Fig. 55).

These couples were garnished with sulphuric acidulated water. The first charge liberated the

hydrogen on the negative surfaces, and scoured them thoroughly; the discharge dissolved some zinc and liberated some mercury, which soon amalgamed the whole surface of the lead supports. The following charges deposited on these supports the dissolved zinc, and the excess of

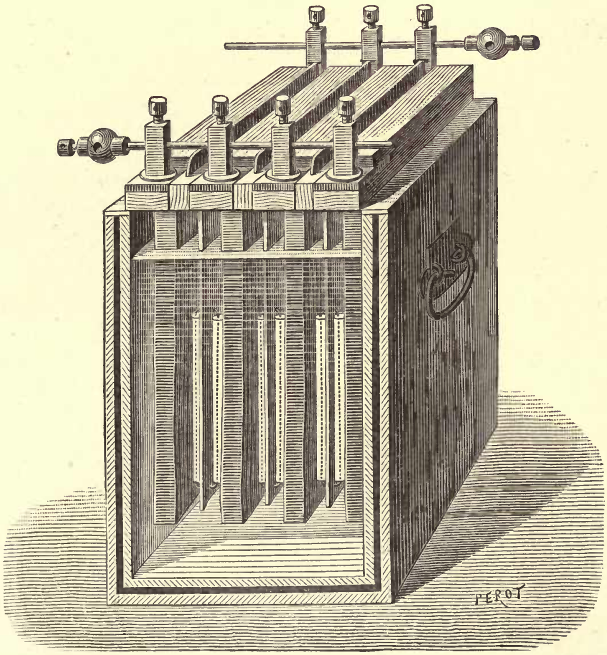


FIG. 55.

mercury kept on the amalgamation; things occurring very much as with Mr. Radiguet's amalgamating support, more recently devised by

him for his primary batteries with chromic mixtures.

The zinc accumulators are now made with Reynier's new pattern of positive plates (Fig. 56).

Couples provided with these comparatively thin plates are much more compact than the old ones. A given size of vessel contains twice as many electrodes.

All the negative plates are constituted by one

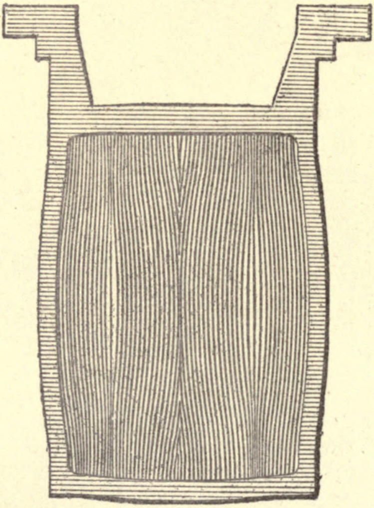


FIG. 56.

single lead strip, folded Greek-wise. The amalgam of zinc pockets have been suppressed. The local actions are attenuated: 1, by the use of distilled water and pure zinc; 2, by a salt of mercury solution; 3, by an addition of pure

sulphate of ammonia salt, the protective action of which had been pointed out by the author.*

The following data apply to an 8 positive plate accumulator :

External length	23 millimetres.
Width	23 „
Height..	32 „
Total weight	20 kilogrammes.
Weight of the 8-positive electrodes	9·600 „
Weight of the 9-negative	2·400 „
Weight of the liquid ..	4·300 „
Electromotive force ..	2·37 volts.
Approximate internal mean resistance ..	0·005 ohm.
Regimen of charge ..	16 ampères.
„ „ discharge	40 „
Voltaic capacity	80 ampère-hours.

This accumulator is remarkable for its power ; but its working is poor, and the conservation of its charge imperfect yet.

Its use is indicated in certain particular cases, especially for the regulation of a current, and the prolongation of a service for a short time after the stoppage of the machines. It is half the cost of Planté's accumulators of equal power, and gives a more perfect regulation.

Bailly Accumulators.—The information respecting this accumulator is scarce. The only

* Piles électriques et accumulateurs. 'Expériences sur l'attaque locale des zincs en circuit ouvert.'

specimen seen by the author* was made of a rectangular vessel containing a flat porous cell in which a thick plate of amalgamated zinc was immersed. Some lead scrapings or shavings, pressed between the two vessels, constituted the positive electrode. The porous vase contained a certain quantity of mercury for keeping the zinc amalgamated. This artifice improves the conservation of the charge, but the use of porous cells prevents the multiplication of the electrodes, makes the apparatus heavy, and considerably increases its internal resistance.

The zinc, having no insoluble support, threatens destruction after a few discharges; it must, from time to time, be reversed.

Tamine Solution.—Mr. Tamine has, recently,† given the following solution as suitable for the lead-zinc accumulators :—

Saturated solution of sulphate of zinc	1000 parts.
Dilute sulphuric acid, $\frac{1}{10}$ solution..	500 ,,
Sulphate of ammonia	50 ,,
Sulphate of mercury	50 ,,

The sulphate of ammonia, and the sulphate of mercury are first dissolved; the solution is poured

* At the Ville de Paris Chemistry and Industrial Physical Laboratory.

† 'L'Année électrique,' Ph. Delahaye, 1888.

in the acidulated water, after which the sulphate of zinc is added.

This liquid does not differ much from that used by Mr. Reynier.

Alkaline Zincate Accumulators — de Lalande and Chaperon Recuperative Accumulators.—The zinc couple—potash solution—oxide of copper is energetic and constant. Messrs. de Lalande and Chaperon, who are the first to have used this voltaic combination, have succeeded in making of it a very good primary battery, the reversibility of which they mentioned. *

Fig. 57 illustrates one type of these batteries.

A is a watertight tank of copper or sheet-iron; it constitutes the external vessel of the battery, and its positive electrode. The bottom is covered with oxide of copper. The horizontal zinc D D is supported, at its four corners, by four isolating blocks L L placed in the corners of the trough; it is folded vertically at one of its ends, which

* French patent No. 143,644, 25th June, 1881, 'Systèmes de piles électriques.' De Lalande and Chaperon, the authors, say, "Our batteries are essentially reversible."

French patent No. 150,454, 3rd August, 1882, 'Perfectionnements aux piles électriques.'—De Lalande. The author mentioned some secondary batteries with alkaline liquors and solid depolarising agents, such as oxides of silver, of mercury, of manganese, of lead, of nickel, of cobalt, &c.

French patent No. 158,945, 3rd December, 1883; same subject, de Lalande. The author claims the amalgamated bronze, or of any other amalgamated metal support for the zinc.

receives the negative terminal M. The trough is three-quarter filled with a solution of caustic potash or soda. This solution must be protected from the action of the carbonic acid in the air by means of a watertight cover, or, which is better still, by a layer of heavy petroleum.

In some other types the electrodes are vertical, the positive being constituted by agglomerates of

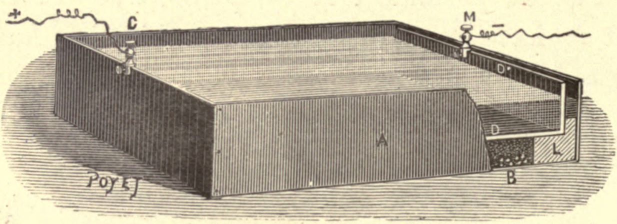


FIG. 57.

oxide of copper (Fig. 58) or by some copper baskets filled with oxidised copper.

The negative electrode is not much attacked in open circuit.

In closed circuit, there is dissolution of zinc with formation of alkaline zincate and reduction of the oxide of copper.

It was at first admitted that these chemical actions could be expressed by the equation :

$$\mathrm{Zn + Ko, HO + CuO = ZnOKO + Cu + HO.}^*$$

* 'L'Electricien,' 1st August, 1883.

According to a new theory of Mr. Finot, the reducive action would be exerted not on the binoxide of copper, but on the protoxide, and would interest two equivalents of copper:

$$Zn + KO, HO + Cu_2O = ZnOKO + 2Cu + HO.$$

The well known de Lalande and Chaperon batteries are constant, energetic, and waste little in open circuit; their electromotive force is only

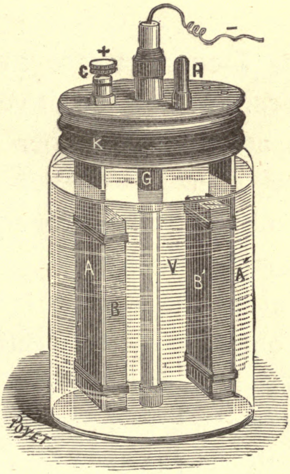


FIG. 58.

0·8 volt but their resistance is very low. They can supply intense currents.

Their description would not have found place in this work had it not been for their reversibility —that is to say, the property which they ought to possess of being regenerable by electrolysis.

It is certain that Messrs. de Lalande and Chaperon have perceived this reversibility, that they have mentioned and studied it; it is equally certain that they have not succeeded in securing it. As accumulators, de Lalande and Chaperon couples have, therefore, nothing more than a historical interest.

Messrs. Commelin, Desmazures, and Bailhache have succeeded in making some reversible alkaline zincate couples.

Commelin, Desmazures, and Bailhache Accumulators.*—The positive electrodes of these couples are porous copper plates obtained by the compression of copper dust under a pressure of 600 kilogrammes per square centimetre (9000 lbs. per square inch).

The material for these plates is some very finely divided metal obtained by the electrolytic reduction of copper scales in a bath of caustic soda. The operation is conducted in large and shallow copper basins; the scales are thrown into this tank, which constitutes the negative pole of the apparatus; a horizontal sheet of copper, suspended at a short distance from the bottom, constitutes the positive electrode. Powder-dust thus obtained is easily cleared by pressure of the small quantity of water

* French patent No. 183,285, 3rd May, 1887, 'Perfectionnements dans les accumulateurs d'électricité [*sic*] et dans toutes les piles électriques en général.'

which it contains. A given weight of it s then spread in a steel mould, in which it is agglomerated by a single pressure.

A sheet of metallic gauze placed in the copper dust aggregates the latter: it consolidates the electrode, and retains the pieces which might become detached by breaking.

The compressed plates are set in a copper frame terminated with a tinned tail.

The porous copper is oxidised, and, in that state, would not give good results. It must be deoxidised before introducing it in the accumulator. To that effect, it is submitted to a previous electrolytic reduction, in a deep tank containing a bath of soda or potash. The impurities of the liquid and of the electrodes fall to the bottom of the tank; the liquid, purified by the operation, is decanted for use.

The necessity of reducing the copper shall be explained hereafter.

The negative electrodes are made of amalgamated tinned cloth of iron wire; the tin holds the mercury, which would not remain on the bare wire.

The cell is made of tinned sheet steel, held together by a system of hooking, and rendered watertight before the tinning, so that no leakage can occur through the attack of the tin. This tank is connected with the negative electrodes resting at the bottom. The particles of electrolysed zinc

which might become detached from their support, fall at the bottom of the tank ; they enter into the discharging circuit, and are taken up again by the liquor.

The composition of the liquid is as follows :

Water	1000
Zinc	144·67
Combined potash	200·82
Free "	313·72

The positive electrodes are enclosed in parchmented paper cells, maintained by vertical glass rods which isolate them from the negative. The parchments are machine sewn. The seams are not watertight at first, but soon become so through the action of the liquid, which causes an intimate adhesion of the paper with itself. The parchment receives, in caustic alkali, a profound alteration—it swells and becomes brittle. But it can remain in that state and act for a long time without breaking, if not disturbed by a mechanical action.

The partitioning is of great importance ; it may be said to be indispensable. Its duty is explained by Mr. Finot's theory.

According to this chemist, the reactions corresponding to the discharge are expressed by the equation :

$$Zn + KO, HO, Aq + Cu_2O = ZnO, KO, Aq + 2Cu + HO.$$

It is not some binoxide of copper, CuO, but some protoxide, Cu_2O, which is reduced. This opinion seems confirmed by the appearance of the electrodes, which are of a pink colour and not black.

The charge, it is true, tends to produce some binoxide of copper; but this binoxide, somewhat soluble in caustic alkalis, is transformed into protoxide by its contact with copper.

$$CuO + Cu = Cu_2O.$$

The protoxide of copper being colloid, cannot traverse the parchment partition. Imprisoned round the copper, it becomes decomposed, as has been said, and does not get mixed with the alkaline zincate. The latter salt, being also colloid, cannot go and diffuse itself towards the copper. The frank separation of the two electrolytes causes a pure zinc deposition, and a neat formation of protoxide of copper. The oxidation of the positive is not thoroughly effected without the parchment cell, and the zinc deposit is sullied with copper; whence a want of adherence and some parasite local actions.

A couple without partitions being charged, irregularly rises up to 2·8 volts; as soon as the charge is interrupted, the electromotive force rapidly decreases — passing from one value to another by jerks, and falling down to 0·1 volt.

The binoxide of copper is not the active agent

of the positive electrode; it could not even exist in contact with reduced copper. Its presence in important quantities in the plates would prevent the regular working of the couples; whence the necessity of a previous reduction of the positive plates before mounting.

Mr. Finot does not appear converted to his own theory, for he has recently, promoted another one:*

"During the charge of the copper accumulator may be observed," he says, "a curious phenomenon which it may be useful to describe, as it would have a tendency to demonstrate that if the oxygen is not combined with the copper, it may very possibly be occluded, owing to the particular properties of the porous plates.

"In effect, when charging the apparatus, the level of the liquid rises from the beginning, and continues its progressive ascension until the charging is stopped. The inverse phenomenon is observed when discharging. The level of the liquid gradually decreases, and reaches the starting point only when the accumulator is fully discharged. If the oxygen combined with the copper, no rising of the liquid would take place at the beginning, and the level would rise only when the whole of the copper is combined. Then only, the oxygen filling the pores of the plates would

* 'Bulletin de la Société Internationale des Electriciens,' meeting of the 7th December, 1887.

increase the volume of the liquid in taking its room. At the discharge, on the contrary, the oxygen should immediately disappear, and the liquid take again its normal level a few minutes after the closing of the circuit. But this is not what happens."

These observations appear insufficient to demonstrate the occlusion of the oxygen in the positive. Could not the ascension of the liquid during the charge be more simply explained by the change of volume of the two electrodes, one oxidised, the other covered with zinc? In the model of accumulator which will be described, the volume of the positive plates is about 330 cubic centimeters; their weight increases, and their density very probably decreases, when, owing to the charge, they pass into a state of oxidation; the resulting increase of volume, added to the volume of the deposited zinc (80 cubic centimeters according to calculation) might justify a perceptible ascension of the liquid in narrow cells the total section of which is 120 square centimeters only. To settle the question, the densities of the liquid and of the positive plates should be determined after the charge; the total volume of the electrodes (liberated zinc included) and of the liquid should be deducted. These easy calculations might do away with the hypothesis of an occlusion of oxygen in the positive plates.

The following complete data apply to a large

model of great output, combined for the propulsion of a torpedo boat of the French navy.

Total weight of the accumulator		10 kilogrammes.
Weight of the 5 positive plates not charged		1·925 ,,
Weight of the 6 negative plates idem		1·050 ,,
Sizes of positive plates (density about 6).	height	280 millimètres.
	width..	125 ,,
Sizes of negative plates	height	300 ,,
	width..	125 ,,
Surface of the positive electrodes		35 square decimeters.
,, ,, negative ,, ..		37·5 ,, ,,
External size of jar	length ..	150 millimètres.
	width ..	085 ,,
	height ..	400 ,,
Weight of the jar		1 kilogramme.
,, ,, liquid (with potash) density 1·55		6 ,,
Weight of the 11 electrodes and of the paper		3 ,,
Electromotive force in open circuit		
Utilisable fall of potential ..		0·75 volt.
Regimen of charge		15 ampères.
,, ,, discharge		48 ,,
Output per square decimeter of electrodes		0·67 ,,
Duration of the charge		30 hours.
,, ,, discharge.. ..		$9\frac{1}{2}$,,
Total voltaic capacity		450 ampère-hours.
Utilisable		413 ,,
Electrical power at the discharge		3·67 kilogrammètres per second.
Total electrical work		0·42 horse-power hour.
Weight of plates corresponding to the work of 1 horse-power hour		7·083 kilogrammes.

Total weight corresponding to the work of 1 horse-power hour	23·800 kilogrammes.
Weight of plates corresponding to the power of 1 electrical horse-power	60·700 „
Total weight corresponding to the power of 1 electrical horse-power	204 „

The above figures have been communicated by Mr. Commelin. The liquid used is a basis of zincate of potash; zincate of soda appears to have been abandoned, as its corresponding charge and discharge regimens are low and it produces creeping salts.

The practical trials have given somewhat different results; they confirm the fact that in these, as in other accumulators the output may be forced, but at the cost of an important loss out of the total weight.

Thus in the experiments carried out at Le Havre in September, 1887, on board a small torpedo boat* the following figures occurred:

Weight of accumulators corresponding to 1 horse-power hour work	33 kilogrammes.
Weight of accumulators corresponding to 1 horse-power work	166 „

* 'Le Figaro,' 23rd September, 1887.

In the experiments carried out on shore, in March last, on a 10-ton battery intended for the propulsion of a submarine boat the following results were obtained:

Weight of accumulators corresponding to 1 horse-power hour's work	37 kilogrammes.
Weight of accumulators corresponding to 1 horse-power	170 „

The weight of 166 to 170 kilogramme per horse-power is not extraordinary, and had already been obtained in November, 1886, with Reynier's light plate accumulators during some experiments carried out at the Concorde Bridge.

But as regards the weight in respect of the horse-power hour, the C.D.B. accumulator is superior to the majority of lead couples.

It must not be concluded, from the foregoing, that the alkaline zincate accumulators will supersede those of the Planté type. Industrially considered, the following points must be taken into account.

1. *The weights:* It has been seen that the F.S.V. accumulators, and those of Fitzgerald, can, in certain conditions, be advantageously compared with the C.D.B.

2. *The volume:* The lead accumulators are, for a given weight, less cumbersome, having denser electrodes and containing less liquid.

3. *The efficiency:* From all the information in

our possession, it appears to be about the same in the two kinds.

4. *The cost:* The cost of the C. D. B accumulators is not known, but copper and potash are much more expensive than lead and sulphuric acid.

5. *The duration:* Planté's type of accumulators are vulnerable through their positive plates; but the latter have been considerably improved of late. The C D B's positive seem to be more durable; but how will the necessary amalgamation of the negative behave? How long will the parchments last? What will become of the liquid, incompletely protected from carbonisation? Do not the assertions of the inventors as to the longevity of so young a system require some practical confirmation?

The great and deserved success of the C. D. B. accumulators and their adoption for naval warfare should not be a cause for relaxing the industrial and technical study of the other systems. Messrs. Commelin, Desmazures and Bailhache have, in the way inaugurated by Messrs. de Lalande and Chaperon, obtained immediate results which testify to great cleverness; by the exercise of equal cleverness in developing the qualities of the other systems of accumulators the result would no doubt be to obtain some much lighter and very much cheaper accumulators.

Before closing this chapter, we must repeat that

the positive plates of these zincate accumulators may be constructed of metals other than copper. Mr. Desmazures, in his patent, claims the use of agglomerated platinum, silver, cobalt, nickel, aluminium, manganese, iron, &c., powders.

The electromotive force of silver is greater than that of copper, but the former metal is heavier, and especially much more expensive, than the latter for a similar number of chemical equivalents; Mr. Desmazures has, notwithstanding those drawbacks, indicated its use for the accumulators intended for the lighting of workmen in mines.

PART III.

TECHNOLOGY.

CHAPTER VII.

TECHNICAL GENERALITIES CONCERNING ACCUMULATORS.

CONSTANTS: ELECTROMOTIVE FORCES; RESISTANCES—POWER—VOLTAIC CAPACITIES—WORK—DISCHARGE DIAGRAMS—CHARGE AND DISCHARGE REGIMENS—CONSERVATION OF THE CHARGE—EFFICIENCIES: MAXIMUM EFFICIENCY PROPER; NORMAL EFFICIENCY PROPER—PRACTICAL EFFICIENCIES—WEIGHTS IN RELATION TO POWER AND WORK—LIFE OF ACCUMULATORS: THEIR REDEMPTION—FORMULA OF EFFICIENCY OF A SYSTEM OF ACCUMULATORS.

THE preceding chapters give, on the best known accumulators, some numerical data which might be found sufficient in practice; but the arrangement of these indications is not sufficiently compact for anyone to easily take a general survey of the question.

In this third part, the data spread out in the book are brought together, completed, and compared. The concrete notions acquired by the reader will enable him to accept these generalisations with their appropriate technical form.

Constants.—The electromotive force is approximately the same for all the accumulators of similar genus; the resistance, on the contrary,

depends upon the setting up of the couples, their dimensions, and other particularities.

Electromotive forces.—We must distinguish :

1. The electromotive force proper—which is that of a charged accumulator, measured on an open circuit, or on a circuit of great resistance, some time after the cessation of the charge.

2. The mean utilisable fall of potential in normal discharge.

3. The minimum difference of potential during a very slow charge, made with a source of electromotive force slightly exceeding that of the accumulator.

4. The mean difference of potential during a normal charge. These various values are known for the three first kinds ; but the information respecting the fourth is incomplete and not very precise.

Genus.	Electromotive force.	Mean utilisable fall of potential.	Minimum difference of potential during a very slow discharge.	Mean difference of potential during a normal charge.
	volts.	volts.	volts.	volts.
Planté lead-lead ..	1·86	1·8	1·95	2·2
Lead-copper	1·26	1·2	1·42	1·6
Lead-zinc	2·37	2·3	2·4	2·6
Alkaline zincates ..	0·8 (?)	0·75(?)	2·4	1 (?)

* See the note: 'Sur les variations de la force électromotrice dans les Accumulateurs' in 'Piles électriques et Accumulateurs.'

In the accumulators of the Planté type the degree of formation should be taken into account. The values given here have been obtained from couples of an average formation, the liquids of which had received no addition of any adjunct; a thorough formation would give a slight increase in these figures; the composition of the liquids also influences the values of the electromotive force.

Resistance.—The resistance of accumulators depends on the composition of the liquid, on the surface and distance of the plates, on the temperature and, for couples of the Planté type, on their degree of formation.

In a given accumulator, the resistance is very variable. It is smaller during the discharge than during the charge; sometimes a period of diminution occurs at the beginning of the discharge, but it is always greater at the end than at the beginning.

A long period of rest much increases the resistance of accumulators of the Planté type. This phenomenon is due to the spontaneous sulphatation of the active materials. After one or two new charges, the resistance returns to its ordinary values.

The resistance of an accumulator cannot therefore be predicted. Many manufacturers are silent upon that point; they might, however, as a piece

of information, mention an average figure which might guide those interested.

In the four kinds of accumulators studied, the resistance is generally very low: 0·05 to 0·001 ohm, according to the patterns and sizes.

Power.—Power must not be mistaken for work. Power is homogeneous to the product of a force by a speed, or to the quotient of a work by a time.

The power of an accumulator, expressed in watts or volt-ampères, is given by the formula.

$$P = eI,$$

in which e is the fall of potential in volts, in the exploited circuit, and I the intensity of the current in ampères.

The powers of 1 kilogrammeter per second, 1 horse-power, and 1 kilowatt, are respectively equal to 9·81 watts, 736 watts, and 1000 watts; whence:

$$\begin{aligned} P &= eI \text{ watts} \\ &= \frac{eI}{9{\cdot}81} \text{ kilogrammeters per second,} \\ &= \frac{eI}{736} \text{ horse power,} \\ &= \frac{eI}{1000} \text{ kilowatts.} \end{aligned}$$

e and I may vary considerably in the discharges of a same accumulator. This point will be again considered when on the subject of regimens.

The value of e I would be maximum, for a given accumulator when $e = \frac{E}{2}$.

E being the electromotive force of the considered accumulator. The external power, in watts, would then be:

$$P = eI = \frac{E^2}{4r},$$

r being the resistance, supposed to be known, of the accumulator.

But this condition of discharge is impossible of realisation, even for a few minutes.

With the known accumulators, the power which cannot be exceeded, corresponds to $e = E \times 0{\cdot}9$. The normal powers generally correspond to values of e approximating $E \times 0{\cdot}96$ (see the previous table).

Voltaic Capacities.—A distinction must be made between:

1. The total capacity—which is that obtained with a discharge of the accumulator pushed as far as possible.

2. The useful or normal capacity—which is that supplied by the discharge of a well-charged accumulator working at its normal regimen; discharge stopped before the fall of potential has decreased more than 5 to 6 per 100 below its

average value. The useful or normal capacity is the true capacity of the accumulator, that which must be understood when no other qualification is applied to the term voltaic capacity.

3. The capacity of charge, or quantity which may be made to pass through a couple normally discharged, before it refuses the charge. (The refuse is marked by a copious disengagement of gas, showing that the active materials are completely charged and cannot any more fix the products of electrolysis).

Useful or Normal Voltaic Capacity. — The voltaic capacity varies, in accumulators of a given genus and weight, according to the structure and the formation of the apparatus.

For the species of the Planté genus, it is customary to give the capacity in reference to the weights of the electrodes. But the comparisons between accumulators of different kinds are given in respect of the weights of the complete accumulators—for, in the three kinds having one soluble electrode, the comparative weight of the liquid and of the vessel, are greater than in the Planté genus.

The capacities of the various accumulators have been indicated at the time of their description. As a more general indication we give hereafter the capacities per kilogramme of accumulator.

Planté	genus	from	2	to	17	ampère-hours.	
Lead-copper	„	„	3	„	8	„	„
Lead-zinc	„	„	3	„	8	„	„
Alkaline-zincate	„	„	0	„	41	„	„

It will be seen, further on, that the regimen of discharge have an influence upon the utilisable voltaic capacity.

Work.—The utilisable electrical work of an accumulator is expressed in volt-coulombs or joules by the formula

$$W = Qe,$$

in which Q is the voltaic capacity in coulombs, and e the mean fall of potential in the external circuit.

The quantity Q is equal to the product of the mean intensity of the current I expressed in ampères, by the time t given in seconds: $Qe = Ite$; 1 kilogrammeter = 9·81 joules; 1 horse-power-hour = 270,000 kilogrammeters; 1 ton meter = 9180 joules. The external electrical work of an accumulator may, therefore, be calculated in joules, in kilogrammeters, in horse-power hours and in ton meters by the formulæ:

$$\begin{aligned} W &= Qe = Ite \text{ joules,} \\ &= \frac{Qe}{9\cdot81} = \frac{Ite}{9\cdot81} \text{ kilogrammeters,} \\ &= \frac{Qe}{2,647,700} = \frac{Ite}{2,647,700} \text{ horse-power hour,} \\ &= \frac{Qe}{9810} = \frac{Ite}{9810} \text{ ton-meters.} \end{aligned}$$

Discharge Diagrams.—The diagram of the discharge of an accumulator or of a battery is obtained by marking in abscisses the times, and in ordinates the fall of useful potential, and the intensity of the current. Other calculated values, such as the power expressed in watts or in kilogrammeters per second, may be inserted between the same co-ordinates.

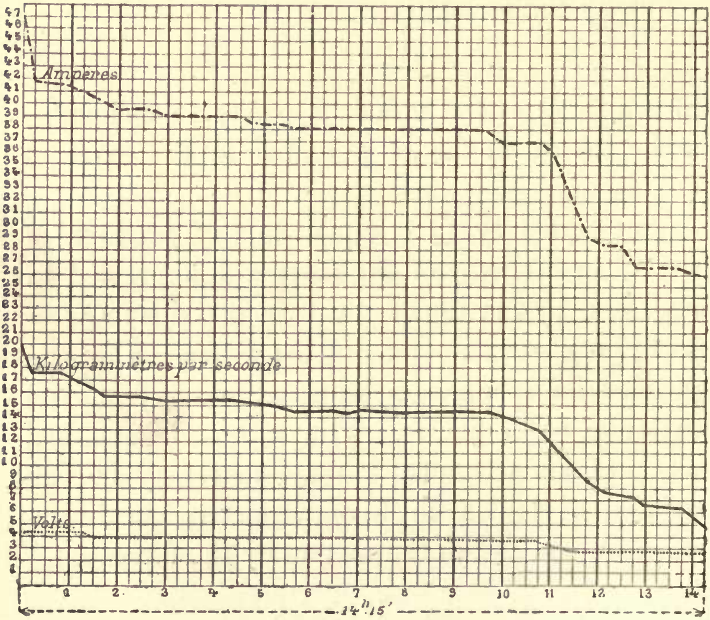


FIG. 59.

Fig. 59 is the diagram of the discharge given by two old Faure-Volckmar accumulators dis-

charged in series.* The discharge was effected immediately after the charge: thus the curves indicate, at starting, the effects of the fugitive super-elevation of the electromotive force due to the primary current; they are sustained, well stretched, for a certain length, then, from a certain point, fall rapidly. This is the critical point at which, in practice, the work of the couples should be stopped.

The voltaic capacity is proportional to the area of the intensities curve; the external electrical work is proportional to the area of the powers curve.

Charge and Discharge Regimens.—For one same accumulator, the normal intensity of the charging current is always smaller than that of the discharging one.

The practicable regimens are higher in proportion to the development of the electrode's surfaces. For a given weight, thin plate accumulators admit and emit more intense currents than thick plate ones.

The composition of the liquids has still more influence on the regimens, than on the electromotive force of accumulators.

The regimen of charge may, in the couples of the three first kinds, vary between 0·2 and

* Experiments carried out in October 1883, by Messrs. Fichet, Hospitalier, and Jousselin.

1·5 ampère, and the regimen of discharge between 0·4 and 3 ampères per kilogramme of accumulator.

In the accumulators of the last genus, the regimens appear to be:

	Charge.	Discharge.
With the zincate of soda	0·5 to 1 ampère	2 to 3 ampères.
" " potash	1 to 2 "	4 to 6 "

The moderate regimens only give good results as to regularity of current, work, and efficiency of the batteries.

The diagrams Figs. 60 and 61 (pp. 148, 149) illustrate the influence of the regimen. They illustrate the expression of the discharge of a Fitzgerald accumulator weighing 10·285 kilogr., and containing 6·725 kilogr. of plates *.

The discharges with a forced regimen (Fig. 61) give a less useful work and, consequently, a poor efficiency. At the same time they cause a diminution in the duration of the electrodes.

Conservation of the Charge.—Considered from the point of view of the conservation of the charge, the Planté type is the best, the lead-zinc the worst.

The conservation of the charge mainly depends upon the degree of formation of the couples, and upon their internal and external isolation.

* Experiments by Mr. G. Philippart.

In incompletely formed accumulators, the heterogeneity of the plates determines some parasitic local actions which more or less quickly exhaust the charge.

The nature of the isolating substance, and of the containing vessel, has a great influence upon the conservation of the charge; glass, porcelain, compact sandstone, ebonite, caoutchouc, and gutta percha are good materials; wood is inferior; tissues and felt are bad.

In order to avoid losses through external derivations, it is a good precaution to place the accumulators upon blocks of impermeable material; when the vessels are metallic, this becomes indispensable.

It would occur that if a primary battery with a high resistance, and a higher electromotive force was opposed to an accumulator at rest, the spontaneous discharge ought to be attenuated;* this presumption has, however, not been submitted to experimentation.

Efficiencies.—There are:

1. The maximum efficiency proper of accumulators;
2. Their normal efficiency;
3. Their practical efficiency.

* Prospectus of the 'Sociéte La Force et la Lumière,' Exposition d'Electricité, 1881.

L 2

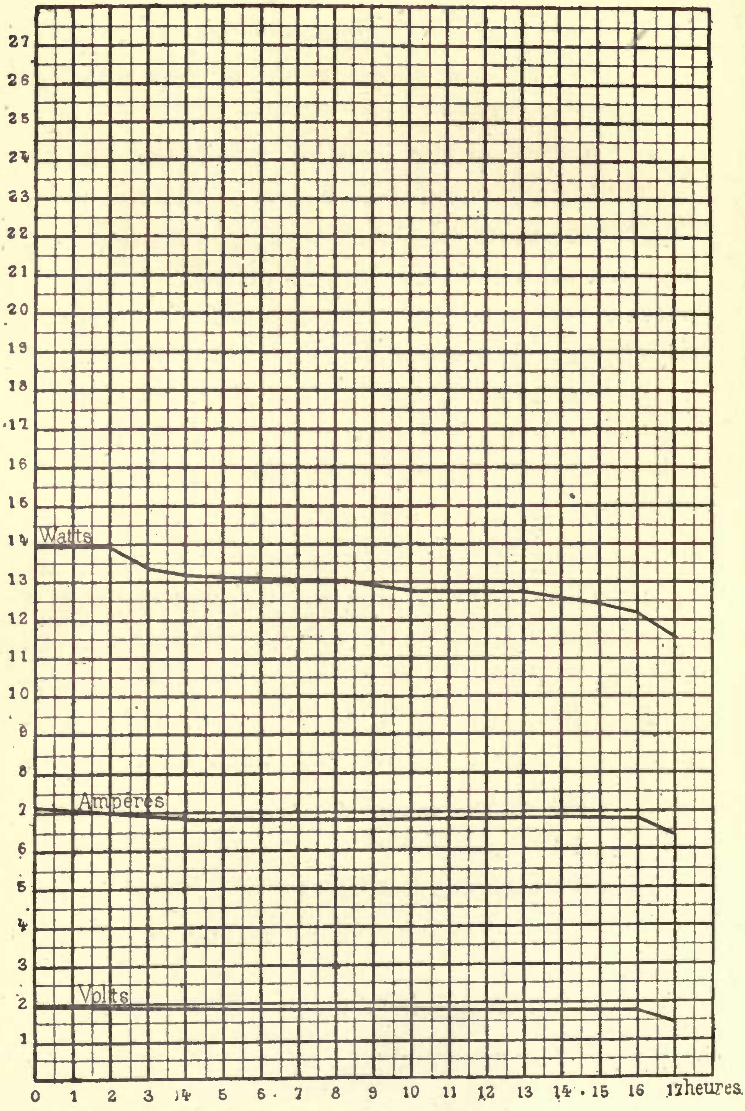

27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
Watts
Ampères
Volts
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 heures.

FIG. 60.

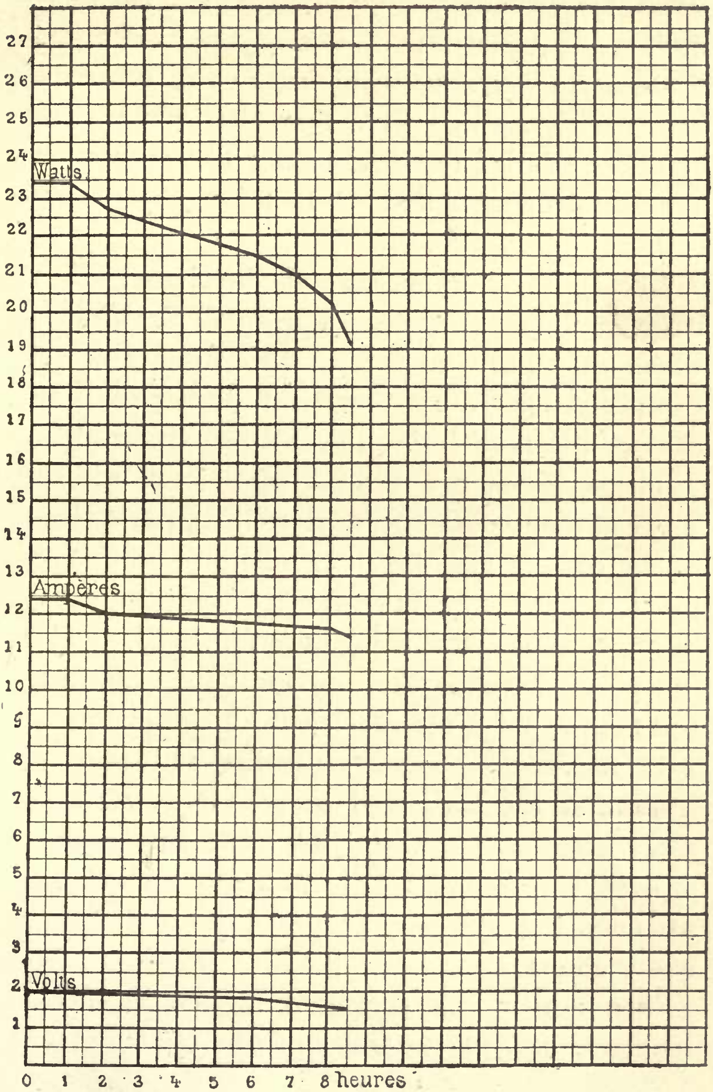

27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
Watts
Ampères
Volts
0 1 2 3 4 5 6 7 8 heures

FIG. 61.

Maximum Efficiency Proper.—In all accumulators, the secondary electromotive force is higher during the charge than during the discharge; whence the necessity of giving to the source a higher electromotive force than that which shall be utilised during the discharge. The proportion between the second and the first forces is the coefficient of reduction.

Accumulators do not take all the charge which is given them; they do not keep all the charge which they have taken; parasitic discharges incessantly occur, during any rest, during the discharge, and even during the charge.

These losses are caused by: local actions between the liquid and the electrodes, derivations inside or outside the accumulator, &c. The result is that the quantity of electricity (coulombs) restored is smaller than that furnished. The proportion between the first of these quantities, and the second is the coefficient of restitution.

If the coefficient of reduction and that of restitution are measured separately *in the most favourable conditions*, and we make the product of these two factors, we obtain a fraction which is the maximum efficiency proper of the accumulator under observation.

The author has measured the coefficient of reduction in the three first kinds.* He found:

* See 'Sur les variations de la force électromotrice dans les Accumulateurs,' in 'Piles électriques et accumulateurs.'

Planté genus	0·95
Lead copper	0·87
Lead zinc..	0·98

The coefficient of restitution was only measured for the first genus. Mr. Planté found it equal to 0·885 for a normal discharge. In slow discharge it can reach 0·92. The maximum efficiency proper of accumulators of the Planté genus would therefore be:

$$0{\cdot}92 \times 0{\cdot}95 = 0{\cdot}87$$

It must not be forgotten that the maximum efficiency proper is a limit which could not be reached in practice.

Its value cannot be determined for the three last kinds for the want of one factor: the coefficient of restitution of the second and third kinds, the coefficient of reduction of the fourth.

Normal Efficiency Proper.—If the reduction and restitution are measured in the conditions of the normal charge and discharge, the normal coefficients of reduction and restitution are obtained.

The normal coefficients of reduction may be deducted from the figures given page 138.

NORMAL COEFFICIENT OF REDUCTION.

Planté genus	=	1·8 : 2·2	= 0·818
Lead copper	=	1·2 : 1·6	= 0·750
Lead zinc	=	2·3 : 2·6	= 0·885
Alkal. zincate.. ..	=	0·76 : 1	= 0·760

The normal coefficients of restitution, known only for the first and fourth kinds, are respectively 0·88 and 0·92. Wherefrom,

NORMAL EFFICIENCY PROPER.

Planté genus ..	= 0·818 × 0·88 = 0·720
Zincates	= 0·760 × 0·92 = 0·699

Practical Efficiencies.—Practical efficiencies are inferior to normal efficiencies proper because their coefficients of reduction are independent from the accumulator.

These coefficients vary in number and value according to the transformation of energy necessary to each kind of application.

For instance, the coefficients of reduction are smaller in number and importance in the case of lighting, than in an application to the traction of vehicles.

So that each accumulator possesses only one maximum efficiency proper, only one normal efficiency proper, and several practical efficiencies, variable according to the uses to which it is applied.

The practical efficiencies shall be indicated, for a certain number of particular cases, in the chapter of applications, the 8th.

Weights in Relation to Power and Work.—It is useful to estimate the weights of accumulators in relation to their power and work.

The relations vary according to the adopted regimens. By increasing the output the power is increased, but the work is reduced, as well as the efficiency and the duration of the accumulators.

The following are the weights respectively corresponding to the power of 1 horse-power, and to the work of 1 horse-power hour, for some known species—values established for acceptable regimens.

Designation of the Accumulator.	Weight of accumulator corresponding to the power of 1 horse-power.	Weight of accumulator corresponding to the work of 1 horse-power.
	kilogrammes.	kilogrammes.
Planté, spiral pattern, very well formed	200	180
Voltameter regulator,* Planté pattern, Ville de Paris model ..	110	180
Reyneir, light plate pattern	208	63
Denis Monnier lighting	525	85
Faure, 1881	540	108
Faure-Sellon-Volckmar lighting ..	408	62
,, ,, ,, tramcar ..	260	43
,, ,, ,, experimental	200	25·5
Fitzgerald	200	31·5
Reynier, lead-zinc	163	80
C. D. B., potash-zincate (laboratory experiment)	204	23·8
C. D. B. potash-zincate (industrial experiment)	170	37

* See page 171.

Life of Accumulators.—The data concerning the life of accumulators are only known for the three first kinds, the fourth being of recent application and not having been submitted to the tests necessary for appreciating their solidity.

In the accumulators of the first, second, and third kinds, the negative plates last a long time; the positive, on the contrary have a limited duration.

The renewals of positive plates considerably increase the price of the services rendered by accumulators.

In order to attenuate the cost of maintenance the makers must construct these electrodes economically, and make them interchangeable so as to replace them with the least amount of trouble.

For a given accumulator, the life of the positive plates depends upon the regimens of work and the conditions of use; so that it is difficult to give, in this respect, much precise information.

Some makers guarantee, for the positive plates, 1000 hours' discharge for batteries submitted to carriages and shocks (electric locomotives, &c.); and 2000 hours' for the working in stationary positions; but guarantees can, in such matters, only be consented to by the makers under certain conditions of use.

Redemption.—According to these vague figures, the redemption of a battery of accumu-

lators (the positive plates of which only being subjected to frequent renewals) would vary from 20 to 100 per cent. per year.

Formula of Merit of a System of Accumulators.—In order to compare the various systems of accumulators, the engineer must find respecting each of them, the following items.

E, electromotive force.
e, utilisable fall of potential.
Q, voltaic capacity.
I, normal intensity of the discharging current
i, normal intensity of the charging current.
P, power.
W, work.
Normal coefficient of reduction.
,, ,, restitution.
Price of accumulators.
Cost of renewal of the positive.
Probable life of the positive and of the whole.

From which he will deduct :

Normal efficiency proper.
Weight in function of power
,, ,, work.
Price ,, power.
,, ,, work.
Rate of redemption.

With these values, the formula of merit of any given system can be established by giving to each item the importance which it requires according to the intended application.

A judicious selection among the competing systems may then be made.

PART IV.

APPLICATIONS.

CHAPTER VIII.

APPLICATIONS OF ACCUMULATORS.

General Remarks on the Charge of Accumulators—Application of Secondary Couples by Mr. G. Planté—Applications to Scientific Researches—Applications to Telegraphy, Telephony, Clockwork, &c.—Application to Electric Lighting—Application to the Current Regulation of Machines: Regulating Voltameters—Welding of Metals—Production of Motive Power—Electrical Locomotion on Tramways—Electrical Locomotion on Roads—Electrical Navigation—Future Application of Accumulators to Aerial Navigation—Translation and Distribution of Energy by Means of Accumulators: Land-carriage of Energy—Water-carriage of Energy—Caption of Natural Forces by means of Accumulators.

General Remarks on the Charge of Accumulators.—Before reviewing the principal application of the voltaic accumulator it may be useful to call to mind a few notions respecting the charge of the couples.

Accumulators can be charged by primary batteries or dynamo-electric machines, or by continuous current transformers.*

The charging source is opposed, pole to pole, to the battery of accumulators; that is to say, the

* It is not impossible to charge accumulators with alternating currents.

positive pole of the first is connected to the positive pole of the second, and the negative poles are similarly connected.

The electromotive force of the charging source must be from 10 to 25 per cent. higher than that of the secondary battery.

Primary batteries are inconvenient and costly sources of electricity, but suitable for scientific researches and amateurs' installations.

Dynamo-electric machines only are used in large and average size installations. They may be of the permanent magnet, or derived electro-magnets (shunt), or double winding (compound), or of the separate excitation type.

Shunt-dynamos are the most convenient and the most in use.

When compound dynamos only are available, the charging current is taken at the brushes and not at the terminals; the machine, in this case, acts as a shunt-dynamo.

It will always be necessary to take the proper precautions to prevent the return of the current of the battery into the charging dynamo, which may be due to a slackening of the speed, or to any other cause. If there is no good automatic disconnector available, it will be advisable to provide the circuit with one or more safety cut-outs, so as to prevent any secondary current of greater intensity than the primary one to deteriorate the dynamo.

The charging of accumulators with series-dynamos requires certain manipulations which are only practicable to skilled electricians.

The charging dynamos may be driven by any kind of motive power, even the most irregular. Natural forces (water or wind) are economical. Up to the present, steam engines are the most in use. Gas, petroleum, and hot air engines are also beginning to be much used. The somewhat jerky motion of gas engines has no inconvenience when charging accumulators.

First Applications of Secondary Couples by Mr. G. Planté.—When making known the first accumulators, Mr. G. Planté did not fail to point out the usefulness of these precious magazines of electro-chemical energy.

He at first suggested the use of his secondary couples in the room of primary batteries as an advantageous substitute in cases in which a powerful current of short duration is required. In 'Recherches sur l'Electricité,' will be found the particulars of these applications such as: the incandescence of metallic wires and their use for galvano caustic; dental surgery; lighting of obscure parts of the human body; explosion of mines; lighting of candles, &c. (briquet de Saturne); eudiometric analysis of air, &c.; medical uses; production of electric light in certain particular cases; distribution of time; application

to railway brakes (Mr. Achard's patent); galvano-plastic operations; prospecting and drilling in rocks; glass engraving, &c.

Mr. Planté has, for the majority of these applications, indicated the means to be employed.

Applications to Scientific Researches.—It is particularly as a means of scientific researches that Mr. Planté has mostly used his accumulators. With a two-cell nitric acid battery he charges, in quantity, a great number of secondary batteries which are joined in series for the discharge. The connections are easily effected by means of an ingenious commutator, well known to physicists. By turning it one quarter of a revolution forward or backward the coupling is obtained in quantity or in series.

With his secondary couples of low resistances and his commutator, Mr. G. Planté obtains, in his laboratory, tensions of 100, 1000, 2000, 4000 volts with a primary source, the electromotive force of which is inferior to 4 volts.

Accumulators, having become a powerful and commodious means of investigation, have enabled their inventor to realise numerous beautiful experiments, the record of which should be read in his 'Recherches.'

In this work will be found described and explained: the luminous sheathing obtained round one of the wires of a voltameter (40

couples); the luminous globules in the midst of liquids (200 to 800 couples); the globular flames, voltaic egret and luminous figures (800 couples); the perambulating voltaic spark (800 couples); the sheafs of aqueous globules and the steam jets (400 couples); the gyratory motions of an electrified liquid vein (400 couples); the electric freshet (400 couples); the voltaic pump; the electro-silicic light (60, 80, 350 couples, according to the liquid used); the electro-dynamic spirals (10 to 20 couples); the illumination of a Geissler tube with a continuous current (800 couples); the crateriform perforations (400 couples); &c.

Pushing farther his researches with high tensions, Mr. G. Planté has invented the Rheostatic machine, which is one of the most beautiful physical instruments. This apparatus transforms the current of a secondary battery of 600 to 800 couples, and brings it to the potential of electrical machines called statical, so that the highest tensions are obtained by means of a double transformation, with a starting point of 4 volts.

The Rheostatic machine consists, in principle, of a certain number of condensators constituted by strips of mica covered with tinfoil, and arranged so as to be charged in quantity and discharged in tension. This apparatus gives sparks of 1 to 5 centimeters in length.

These beautiful experiments have enabled Mr. Planté to explain several great natural pheno-

mena: globular lighting, chaplet lighting, hail, tornados and cyclones, aurora borealis, &c. These vast studies on Meteorology have been recently published in book form.*

Owing to the considerable industrial importance which they have acquired, during the few past years, accumulators have monopolised, to the detriment of Mr. Planté's purely scientific researches, a portion of the attention bestowed upon them. This portion of his work, although of less apparent usefulness to the vulgar is, for the physicist, a source of most important discovery upon the highest questions of natural philosophy.

Application to Telegraphy, Telephony, Clockwork, &c.—In telegraphic, telephonic, &c., exploitations, primary batteries, the use of which is costly, would be superseded with advantage by secondary ones periodically recharged. This substitution has already been effected at some important exchanges.

The main quality required of accumulators intended for this kind of work is a good conservation of the charge.

The motive power required for the periodical recharging of telegraphic and telephonic batteries,

* 'Phénomènes électriques de l'Atmosphère,' by G. Planté, Paris 1888.

is very unimportant. It has been calculated * that with 1 horse-power working 12 hours a day, the 3000 exchanges of the Paris telephonic system could be fed. This system employs 30,000 primary couples, mostly all Leclanché's.

In telegraphic applications, the practical efficiency of accumulators, from the motive power down to the apparatuses, is the product of three factors :

a. Transformation of mechanical work into electrical energy in the charging dynamo $a = 0{\cdot}85$.

b. Normal efficiency proper of the accumulators $b = 0{\cdot}72$.

c. Coefficient of loss : slow dissipation of the charge in the accumulators, the discharge of which is very slow, and for a long time differed $c = 0{\cdot}7$.

Whence

$$\text{Practical efficiency} = a \times b \times c = 0{\cdot}43.$$

This figure is very advantageous, considering the cost of industrial motive power compared to that of primary batteries, which cost at least two francs per horse-power-hour, cost of manipulations not included.

* Piles électriques et accumulateurs : Sur le travail des piles Leclanché en service sur le réseau téléphonique de Paris,' from experiments jointly carried out with Mr. A. Reynier, 1883.

Application to Electric Lighting.— Electric lighting is, actually, the most important application of accumulators. The use of accumulators has the following advantages. 1st, the security of the light; 2nd, its regularity, the accumulators giving no abrupt variation of electromotive force; 3rd, the independence of the burners: when the surfaces of the accumulators have a great development their resistance is practically nil, so that their output can be regulated accordingly to the number of lamps in operation—the lighting or putting out of a certain number of them does not influence the remainder; 4th, the greater duration of the incandescent lamps, which are protected from destructive variations.

It can be maintained that, alone, the electric lighting by accumulators is safe. That is why it has been made compulsory, in all the theatres, for the rescue service.

The practical efficiency of accumulators, from the motive power to the wiring of the lamps, is the product of two factors.

a. Transformation of the mechanical work in electrical energy in the charging dynamo, $a = 0 \cdot 85$.

b. Normal efficiency proper of the accumulators, $b = 0 \cdot 72$.

Whence

$$\text{Practical efficiency} = a \times b = 0 \cdot 576.$$

It must be observed that the lighting direct by machine had the coefficient *a*; so that the efficiency of the accumulator process compared to the direct process, is really that of the accumulators themselves, or 0·72.

In fact the comparative efficiency is generally higher. For, in the case of accumulators the expense of energy is proportional to the useful consumption, whereas in the direct process this expense becomes relatively much greater as soon as the engineering materials cease to work in full, as it often is the case.

When an important lighting station works for only a few hours daily, the use of accumulators permits of reducing the importance of the station. Thus in a theatre, where the average weekly lighting is about 32 hours, the motive power and dynamos might be of only one-third of what they have to be in the direct lighting process.

Everything being considered, the use of accumulators in electric lighting reduces the cost of the installation, and is a guarantee of security and regularity in the working.

The importance of a battery for a given lighting is easy of calculation. The number of accumulators to be joined in tension is the quotient of the necessary potential by the utilisable fall of each couple. The duration of the lighting being known, as well as the number of lamps, and their consumption in ampères, the voltaic capacity

(ampère-hours) of the required couples, and their output are easily deducted. The type of accumulator selected shall answer these requirements, which do not concord in all cases; if a large output is required for a short time, the couples should be powerful, and they will not be completely discharged; if, on the contrary, only a small output of long duration is required, the accumulators must be of great capacity, and will not work at their maximum power.

Owing to these considerations, a given system may answer in some cases and have to be rejected in others.

When the capacity and the regimen shall exceed those of existing types, or those of handy sizes, several batteries, joined in quantity, may be used.

Application to the Current Regularisation of Machines; Regulating Voltameters.—The speed of a dynamo is rarely uniform; the rhythmed impulsions of the motor, the defects of the transmission, the variations of the resisting work, alternately accelerate and retard its average beat. The variations of electromotive power resulting from these irregularities are more or less marked according to the degree of perfection of the installation; and are more or less acceptable according to the required nature of light.

For instance, if the lighting is effected by glow

lamps, small changes in the speed produce great variations in the brilliancy of the lights, the luminous intensity being nearly proportional to the sixth power of the difference of potential at the two distribution terminals. In lamps with large carbon filaments, these irregularities are attenuated, owing to the mass of the luminous material; but in those with fine filaments, the use of which becomes prevalent, the variations are very noticeable and the more disastrous that they are synchronic in all the lamps.

Accumulators, it is known, regularise the current, for their electromotive force varies in much less proportion than that of the charging motor. In those of the Planté type, the increase in the difference of potential amounts to only 8 per 100 of the excess of the electromotive force of the source. This explains how the lighting carried out with accumulators is always very regular, even with a defective mechanical installation.

It is objected that this regularity would be too dearly paid for if the qualities of accumulators as a fly-wheel only were used to the exclusion of their qualities as a magazine.

For this restricted use, the author of this work has proposed the use of economic secondary couples, the special features of which are a great surface of electrodes, a very low internal resistance, an intense regimen of discharges, a small voltaic capacity, and a small cost.

These couples, which are not, properly speaking, accumulators, have been designated regulating voltameters.

The question of capacity being eliminated in the realisation of regulating couples, the choice of combinations is extended.

Besides accumulators of the Planté type, other voltaic systems may be used. The lead-sulphate-of-zinc couple appears to be the best of all, when a long conservation of the charge is not required. Its high electromotive force, 2·4 volts instead of 1·9 volt, allows of a reduction in the number of the couples and in the resistance of the battery; its variations are even less than those of the couple lead-lead; lastly, when a certain capacity is required to work during 15 to 30 minutes in case of accident, it can be formed right off.

The Reynier accumulator with plaited positive and plain negative plates, described page 118, is a good regulating voltameter. For this particular use, the positive plates are, as a rule, put into service without having been previously formed; they are thus cheaper and last longer.

In order to give these voltameters a certain capacity of accumulation, the positive electrodes are prepared by Mr. Planté's nitric acid method, thus acquiring the property of fixing a certain quantity of oxygen and sulphuric acid; the negatives are formed at once by a deposit of electrolytic zinc. A battery of voltameters, the positive

plates of which have been well prepared, can prolong a lighting during half an hour, a space of time generally sufficient to remedy any defect which may be the cause of a temporary stoppage. With the surface of electrodes mentioned page 119, the zinc-lead couple may regularise a current of 50 to 75 ampères. Its electromotive force, under charge, being about 2·5 volts, 42 of these voltameters could regulate (and, if necessary, prolong) the lighting of 100 to 150 glow lamps of 15 to 16 candles; 50 lead accumulators of a double surface would be required to obtain the same results. The economy resulting from the substitution amounts to 65 per 100.

So the voltameters are indicated as a substitute to accumulators wherever it is intended to regularise a lighting and take precautions against sudden extinctions. The regulating voltameters have already been applied in many instances.

The most important is that of the large battery supplied by the author, in March 1887; for the Paris Hotel de Ville. It is of the type lead-lead, the Administration not daring to adopt the more advantageous type zinc-lead, the practical merits of which had not then been demonstrated.

The couples are of the Planté type, of the classical spiral pattern; but the details of construction have been adapted to the dimensions of the apparatuses and their destination.

The two electrodes of each couples are rein-

forced by hemmings. The tails have been strongly reinforced and protected against the mechanical and electro-chemical causes of destruction. The isolation is secured by two wooden partitions separated by vertical jointed wooden rods; the glass vessels or jars are protected from internal and external injuries, by means of felt buffers; they are closed by a cover, which shelters the whole and moderates the evaporation.

The cells are connected together in three equal and distinct series, by means of strong bolts of lead and antimony alloy.

The electrodes have a considerable surface; 480 square decimeters.

The voltaic capacity can reach one million coulombs. The contract only stipulates for 300,000 coulombs sufficient to maintain the lighting during 20 to 30 minutes in case of an accidental stoppage of the machines; a certain number of voltameters mounted in overcharge are then introduced into the lighting circuits for compensating the loss of electromotive force due to the stoppage of the works.

The Paris Hotel de Ville battery is an example of a remarkable application of secondary couples to lighting. Batteries of 100 horse-power and over will no doubt be largely employed before long, but up to now no other one of that power is known to exist.

The regulation of a current by means of a

battery of voltameters costs a certain quantity of energy, proportional to the intensity of the current which it derives. The stronger the derived fraction, the stronger also and the more abrupt are the primary variations, and the more perfect becomes the necessitated regulation. The said fraction may vary between 2 and 10 per cent. with lead-lead couples, and 1 and 6 per cent. with the zinc-lead couples.

It is empirically adjusted by increasing or reducing the number of voltameters in series, so as to increase or diminish their regulating influence.

When the voltameters are used for prolonging the lighting after the stoppage of the machines, the loss of potential due to the cessation of the primary current must at the proper time be compensated for.

The simplest mode of doing it is to use a few additional voltameters: during the normal working, this battery is joined in quantity with a similar number of couples taken at one end of the principal battery; on the stoppage of the machine, the whole is coupled in tension, so as to obtain the required compensation. The change can be effected by means of any system of two-way commutator.

Welding of Metals.—The calorific effects of currents may be used for the working of metals and especially for welding.

Reference to electrical welding of metals was first made by Planté in 1868:

"The discharges given off by these batteries, are," he said, "of a duration long enough for producing the most intense calorific effects, such as the fusion of platinum rods, iron, steel, &c.

"Platinum may, by this means, be welded to itself with great facility. So can, *à fortiori*, the other metals, less refractory than platinum." *

This process has been introduced into industrial practice by Mr. Elihu Thomson † who succeeded in welding iron, steel, platinum, gold, cast-iron, brass, bronze, copper, German silver, zinc, tin, lead, aluminium, &c.

The bars, tubes, or other pieces which it is intended to weld are firmly pressed against each other. A current of great intensity is made to pass from the clasps of the holder through the junction. The resistance at this point being highest, the two ends soon get to welding heat, and thus are intimately united.

Mr. E. Thomson has welded rods of copper 11 mm. diameter and steel bars of 22 mm. He estimates the current used at 20,000 ampères and $\frac{1}{2}$ volt.‡ This current was obtained with

* Addition of the 29th February, 1868 to the French patent No. 78897, 1867 'Dispositions des batteries secondaires à lames de plomb et ses applications.'

† 'The Electrical World,' translated into 'Revue Internationale de l'Electricité, 20th May, 1887.

‡ This figure seems exaggerated, considering the small sectional surfaces of the pieces welded.

a self-exciting alternating current machine, and a transformator.

The current required for the welding of a steel bar of 38 mm. diameter is stated to be 50,000 ampères, and corresponds to 35 horse-power for less than one minute.

For such short operations, secondary couples would prove more advantageous than transformators. The motive power could be reduced by 95 per cent. Accumulators of small electro-motive force (such as those of the second genus), specially constructed for a large debit and a small capacity, could be utilised ; they would be charged in tension and discharged in quantity. As the normal debit of accumulators may be trebled when it is desired to obtain short discharges without taking any account of the efficiency, some very intense currents could thus be obtained with a cheap battery.

Electric welding may be carried out by means of the voltaic arc. In this case larger electro-motive forces and much smaller intensities are required. This process is more convenient than the other, and applies to more numerous cases. Sir William Siemens, Wallner, Cowles, &c., have applied the voltaic arc to the fusion of refractory metals ; but the first application of the arc obtained from accumulators to welding properly speaking appears to be due to Mr. A. de Méritens who used this process in the manu-

facture of the Tommasi accumulators.* The same process was also in use at Mr. de Kabath's works in 1882.

More recently, Mr. Benardos† has worked out a complete system for the industrial realisation of welding by means of the voltaic arc, applied to the most varied operations.

The current is supplied by a battery of accumulators, the coupling of which may be effected in different manners. The metallic piece to be welded is the negative pole of the arc; the positive pole is a carbon rod mounted in an appropriate holder. The voltaic arc produced between the pieces of metal and carbon is applied on the parts to be welded; it constitutes a kind of powerful blowpipe.

The battery of accumulators is kept in charge of a dynamo working without interruption; it is discharged intermittently and supplies secondary currents of much greater intensity than the primary one. The fall of potential and the intensity are regulated by some couplings and one rheostat.

The accumulators are of small capacities and

* French patent 146,010, 24th November, 1881, 'Mode of welding by Electricity.'

† 'La Soudure Electrique par le procédé Bernardos' paper read by Mr. Rühlmann before the Electrotechnic Society of Berlin, translated in 'La Revue Internationale d'Electricité,' 5th February, 1888. 'Procédés de soudure par l'Electricité' applied by Benardos and analysed by Kamenski. Translation by Przewoski: 'Mémoires de la Société des Ingénieurs Civils,' February 1888.

of large output. Mr. Benardos makes them, like Mr. de Kabath, with lead plates alternately plain and corrugated; but he has replaced the old cages by suspended mountings imitated from Reynier's frames. Any other system of large surface accumulators may be used.

The fall of potential in the arc varies from 40 to 175 volts. The intensity of the current is still more variable, but has not been indicated. It may be from 100 to 1000 ampères. These values are altered according to the nature and the mass of the pieces to be welded.

The diameter of the carbon rod may be greater or smaller; it is sometimes 25 millimeters, and its length 250 mm.

The hand of the operator must be protected by a cardboard shield, and his sight by coloured glass spectacles. When the operation is to last a certain time he uses a silk mask, coated with resin, and provided with a moveable perforated glass frame for breathing purposes. The neglect of these precautions might result in all the consequences of a sunstroke.

Weldings of the most varied kinds are effected with the voltaic arc on refractory or fusible metals alike. Cast iron, for instance, can be welded by this, but not by the ordinary processes.

With iron, steel, and cast iron, the flux used is sand or borax, which facilitate the separation of the slag resulting from the oxidisation of the metal.

The constants of the voltaic arc used being known, its power in calories per second may be calculated.

If e is the fall of potential in volts, and I the intensity of the current in ampères, the calorific power P of the voltaic arc is

$$P = 0 \cdot 243\, e\, I \text{ calory-gramme-degree per second.}$$

Production of Motive-power.—Messrs. G. Planté and A. Niaudet made, in 1873, a beautiful experiment which simultaneously demonstrated the reversibility of both secondary couples and continuous current magneto-electric machines.*

The terminals of a Gramme machine with magnet were connected to those of a Planté accumulator, formed but not charged (Fig. 62). The accumulator was charged by working the machine during a certain time ; the machine being stopped and left to itself, it immediately restarted at a slower speed, and in the same direction as during the charging.

This important experiment, which nowadays does not excite any astonishment, contained the germ of the exploitation of the natural and industrial motive powers by means of accumulators. Theoretically considered, it placed in evidence the antagonism of electromotive forces in a

* 'Sur une expérience d'électro-dynamique,' by G. Planté and A. Niaudet. 'Comptes Rendus de l'Académie des Sciences,' tome lxxxvi., page 1259, 1873.

system composed of a voltaic source and a magneto-electric machine.

The electromotive force of the source is nearly fixed; that of the machine depends upon its speed. For a certain speed of the machine which may be called the critical speed, the electromotive forces are equal; no current passes in the circuit. A greater speed causes the

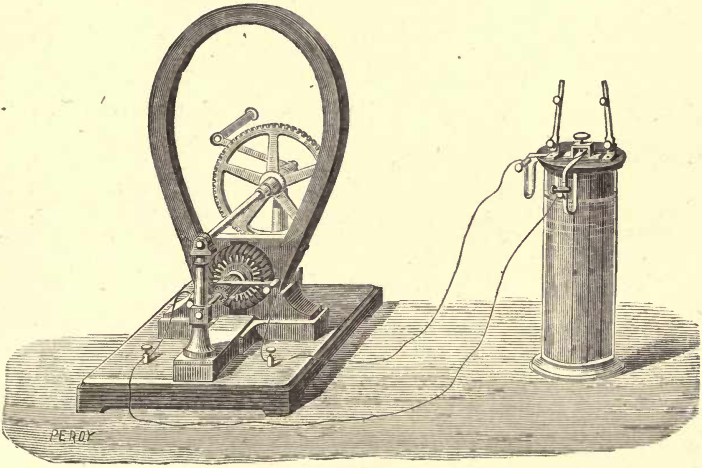


FIG. 62.

electromotive force of the machine to predominate; it then expends some mechanical work, transforms it into electrical energy, and charges the accumulator.

When the speed is, on the contrary, inferior to the critical speed, the voltaic electromotive force predominates; the accumulator discharges itself and supplies some electrical energy, which the

machine—becoming a motor—transforms into mechanical work.

The mechanical theory of these phenomena has been established by Mr. Mascart.*

If we call:

E, the electromotive force of the voltaic battery, expressed in volts;

e, the antagonistic electromotive force of the machine, in volts;

R, the total resistance of the circuit, in ohms;

the theoretical mechanical power, P, of the machine is:

$$P = \frac{e\,(E - e)}{g\,R} \text{ kilogrammeters per second.}$$

The gait of the motor depends upon the resisting work. When the motor revolves empty, its speed becomes such that e becomes nearly equal to E. The small amount of work produced is spent in frictions; the result is the production of heat, and the useful work is nil. If, on the contrary, the motor is blocked to rest, its electromotive force and mechanical work are zero. But the calorific work is a maximum; it is equivalent to

$$\frac{E^2}{g\,R} = \frac{I^2\,R}{g} \text{ kilogrammeters per second;}$$

I being the intensity of the current in ampères.

* 'Des machines magnéto-électriques et électro-dynamiques,' 'Journal de Physique,' July 1877.

The regimens of utilisation are to be found between these two extreme regimens which give no useful work.

In any case, the *theoretical* efficiency of the machine, working as a motor, under the action of a battery of accumulators is :—

$$\frac{e}{E}.$$

Its practical efficiency is the product of three factors :—

a. efficiency proper of the machine which charged the accumulators: $a = 0{\cdot}85$;

b. efficiency proper of the accumulators: $b = 0{\cdot}72$

c. efficiency proper of the electric motor.

This efficiency c itself is the product of two factors.

c'. electrical efficiency of the motor, depending upon its electrical resistance and especially of its gait: $\frac{e}{E}$;

c''. mechanical efficiency of the motor or proportion of the utilisable to the total work (the difference between these two works being absorbed by the passive resistances).

The electrical efficiency $\frac{e}{E}$ may vary between 0 and 1; in practice, when working at favourable speeds, it can be made to be equal to at least $0 \cdot 9$. As to the mechanical efficiency, it is not, in well

constructed machines, in which the frictions are small, inferior to 0.95. Thus—

$$c = c' \times c'' = 0{\cdot}9 \times 0{\cdot}95 = 0{\cdot}855.$$

Consequently the practical efficiency, U, of an electric motor worked from an accumulator is, from the mechanical motor working the charging dynamo up to the pulley of the electric motor:

$$\mathrm{U} = a \times b \times c = 0{\cdot}85 \times 0{\cdot}72 \times 0{\cdot}85 = 0{\cdot}52.$$

In certain cases, this formula is affected by other coefficients of reduction.

The applications of the accumulators to the production of motive power, are too little practised at present; they will play an important part in industry. We will again treat of this subject in the chapters on electrical locomotion on tramways and roads, electrical navigation and captations of the natural forces.

Electrical Locomotion on Tramways.—The application of accumulators to locomotion was proposed by Mr. C. Faure in 1880.* The first industrial attempts are due to Mr. S. Philippart, senior, in 1883.

The author has given the description and the critique of these experiments in "l'Electricien."†

* French patent No. 139,258, 20th October, 1880, 'Perfectionnements aux Batteries galvaniques et applications de ces batteries aux machines locomotives électriques.'

† 1st and 15th September, 1883.

This article, reproduced in 'Piles electriques et accumulateurs,' reviewed the use of variable couplings suitable for supplying the various regimens required by the variations of the resisting work; it also explained the possibility of recuperating, by recharging the accumulators *en route*, a portion of the negative work corresponding to descents on rapid inclines. It combined with an estimate of the cost price and concluded in favour of the traction by accumulators as being cheaper than animal traction in countries where horses are dear to buy and to keep.

These technical criticisms have received a practical sanction, excepting, however, the recuperation by recharging *en route* which has not yet been adopted:—

The following notions are extracted from the said article:—

The sum of energy required for propelling a vehicle on the forward and backward journey, on an accidented rail or tram track is composed of—

1. The traction work proper, W, which is proportional to the weight M of the vehicle, to the length L of the road and to the coefficient of traction k

$$W = M \text{ (in kilogrammes)} \times L \text{ (in meters)} \times k \text{ kilogrammeters.}$$

2. The sum W′ of the elevating works, positive or negative, $w'_1, w'_2, w'_3, \ldots$ reaching from changes of altitudes $h_1, h_2 \ldots$ of the train on the inclines.

The elevating work is the product of the weight M of the vehicle by the difference of level.

$$w'_1 = \text{M (in kilogr.)} \times h \text{ (in meters)} \quad \text{kilogrammeters.}$$

3. The sum W″ of the expenditures of live forces, positive or negative, w''_1, w''_2 . . . . due to the starts and the stoppages. The quantity of live force so expended, each time, is

$$w''_1 = \frac{\text{M (in kil.)}}{2g} \times \text{V}^2 \text{ (speed in meters per second) kilogrammeters.}$$

A train which, starting from a station, comes back to it after a more or less accidented journey containing stoppages, has neither increased nor decreased its energy of position; it has gained or lost no live power. We can write

$$\text{W}' = w'_1 + w'_2 + \quad . \quad . \quad . \quad . \quad = 0$$
$$\text{W}'' = w''_1 + w''_2 + \quad . \quad . \quad . \quad . \quad = 0$$

Theoretically, the work of traction would amount to the rolling proper.

In practice, on the contrary, the works of elevation and starting are considerable, for the accumulators supply to all the positive elevations and all the starts; and the negative works of descents and of stoppages are nearly entirely absorbed by the brakes. A portion of these negative works could, however, be recuperated.

As was seen page 180, the theoretical me-

chanical power P of the electric motor, worked from accumulators is

$$P = \frac{e\,(E - e)}{g\,R} \text{ kilogrammeters per second.}$$

This formula indicates two modes of varying the motive power and the speed of the train.

1. The increase or decrease of E.
2. The decrease or increase of R.

If E is made to vary by adding or subtracting some accumulators, the expenditure becomes unequal in the couples; it is a great loss at the charge and at the discharge. If supplementary resistances are introduced, they become the seat of an emission of heat which, in certain cases, represents a considerable fraction of the total work. Lastly, neither method allows of the recuperation, that is to say, of the accumulators being recharged on rapid descents or abrupt stoppages, since with dynamos excited in circuit e is always smaller than E.

Better results are obtained by means of couplings. The electric motor is provided with a distinct exciting circuit and artificial variations of E and R are concurrently utilised; those of E are produced by some grouping of accumulators giving some distinct regimens; those of R are effected in narrow limits, for the production of graded powers between the defined regimens obtained by the commutations. The various

groupings of the battery are obtained by means of a commutator *ad hoc*, easy of combination. This method has been used by several makers, who claim it as their own without regard to anterior publications. It should be completed by means of arrangements enabling to recuperate a portion of the negative works (descents on stiff inclines and sudden stoppages), by recharging the accumulators *en route*. The battery would take back a portion of its charge by absorbing some transformed mechanical work on the condition of making, at the proper time $e < E$.

The complication of means is only apparent. It is possible to arrange some commutators successively operating the groupings in the required order. By the simple working of a complicate instrument, the pilot could go from the highest positive power to the strongest negative, passing through all the intermediate regimens without having to reason about the effected combinations.

As to the material fittings of locomotives or vehicles, it is a question of special mechanics which is not concerned in the frame of this work.

The prime cost of traction by accumulators comprises firstly the cost of the motive power at the works, the maintenance and redemption of the motive power material; then the accessory expenses of grease, oil, labour, and rents.

The length of a line of tramway and its profile

being known, as well as the kilometric run of the train and its weight in charge, one can, with the formulæ given page 183, calculate the quantity of work daily supplied by the horses. The indirect amount of work to be done by accumulators is deducted therefrom, and the weight of accumulators required results from these estimations.

The mechanical work produced by the factory where the accumulators are charged is very much greater than the work required from the horses. For the successive transformations of energy, from the pulley of the charging dynamo up to the driving wheels, introduce five coefficients of reduction, viz.:

The three already known factors $a = 0 \cdot 85$; $b = 0 \cdot 72$; $c = 0 \cdot 85$.

d, mechanical transmission of the power of the electric motor to the driving wheels $d = 0 \cdot 9$.

F, proportion of the useful weight to the weight carried: the additional weight of the electrical material being nearly the half of that of the train pulled, this proportion is $1 : 1 \cdot 5$ whence $F = 0 \cdot 66$.

Whence:

Practical efficiency from the motive power at the factory up to the driving wheels:

$$= a \times b \times c \times d \times e \times f = 0 \cdot 85 \times 0 \cdot 72 \times 0 \cdot 85 \times 0 \cdot 9 \times 0 \cdot 66 = 0 \cdot 31.$$

The mechanical work required at the charging

station is, therefore, that of the horses multiplied by

$$\frac{1}{0 \cdot 31}.$$

In practice the increase is not so great, and specially if a portion of the negative works is recuperated.

Electrical recuperation is the more important as the track is more accidented. Without any artifice, there is always a little recuperation, in the moderate inclines, by using the declivity of the line.

We are near enough the truth in giving the practical coefficient of increase at $\frac{1}{0 \cdot 40}$ or $\frac{1}{0 \cdot 34}$ according to the case when recuperation is practised or not.

The motive power required at the station being known, the cost of the work of traction may be easily calculated, the other items being given hereafter.

In order to compare the cost of animal traction with that of traction by accumulators it is necessary, in both systems, to deduct the cost of the useful horse-power hour.

This comparative estimation has been made, for Paris, in the paper mentioned. We found :

Cost of the useful H.P. hour, animal traction	2 *f* 0.0 *c.*
,, ,, ,, ,, accumulator ..	1*f.* 29 *c.*

The economy in favour of traction by accumulators is 35 per cent.*

Besides this important economy, the traction by accumulators is possessed of special advantages which we have not here to dissert upon.

Electrical Locomotion on Roads.—Upon well kept roads, such as the national French routes, the coefficient of traction of a free carriage, provided with good wheels, is not very high; on asphalted or wood paved roads the rolling effort is small, often smaller than on tramways.

The electrical locomotion of carriages seems therefore to be possible; it has, in effect, been realised by several amateurs.

The difficulty special to road locomotion is the recharging of accumulators.

A tramcar returns to the station from five to twenty times per day; the renewal of its provision of energy is secured. A carriage, on the contrary, runs to all kind of places, and, in the actual state of the question, charging stations are not to be frequently met with.

The distribution of electric energy in towns would enable some charging stations to be established, here and there, but then it would be necessary that accumulators should be quickly charged. Those which we know can only be slowly charged.

* Since 1883 some figures require altering, but the differences above and under nearly compensate each other.

The apparent solution would, then, be to replace exhausted accumulators by newly charged ones, which substitution could be effected at a given price

Even this solution would not be complete, as a carriage with accumulators would have to keep within certain limits, and would not have the independence of a thermic motor which can easily renew its provision of energy.

Electrical Navigation.—The mechanical difficulties in electrical navigation are nearly nil. The important condition to realise is the specific lightness of the battery.

The calculations relating to electrical navigation have for their basis some known formulæ which we will briefly review.

The useful effort $F u$ necessary to propel a boat in large and still waters, is given by the expression :

$$F u = k \frac{A V^2}{2 g} \text{ tons,}$$

in which

A, is the area of the immersed midship section, in square meters.

V, the speed in meters per second.

k, coefficient, which much varies according to the shape of the vessel.

The smallest value obtained for k is 0·045.

The finely-built vessels for sea racing have

$$k = 0 \cdot 10 \text{ to } 0 \cdot 16.$$

The values of k increase when the section of the channel is not very large compared to A. With swift boats, running in narrow waters, k reached 0·20 and even 0·27 (Morin).

The useful motive-power is proportional to the exertion and to the speed; it is thus:

$$P u = F u V = k \frac{A V^3}{2 g} \text{ ton-meters per second.}$$

$$= \frac{k A V^3}{2 g} \times \frac{1000}{75} \text{ horse-power.}$$

The useful work $W u$ is the product of the useful exertion by the space run L (which is expressed in meters).

$$W u = F u L = k \frac{A V^2}{2 g} \times L \text{ ton-meters}$$

$$= k \frac{A V^2}{2 g} L : 270 \text{ horse-power hours.}$$

These expressions have been verified up to speeds of 7 to 8 meters per second which are not exceeded in practice. In rivers, the water has a speed proper, u. To obtain a speed V' of the vessel, measured on the shore, a speed of $V + u$ or $V - u$ must be produced according to the vessel running against or with the stream, V being the speed of the vessel proper.

In the case of river navigation, V must be replaced by

$$V' = V \pm u.$$

The formula governing an electric motor worked from accumulators is

$$P = \frac{e\,(E - e)}{g\,R}$$

which has already been explained.

The expressions of the values of P u and W u indicate the great difference existing between electrical navigation and land locomotion. The principal differences are well illustrated in the example given page 193.

It will, from these considerations, be understood why some trials of *petite vitesse* navigation have succeeded, with ordinary primary or secondary batteries, by amateurs or inferior technical people.

Grande vitesse navigation with large vessels of elongated shape could only be actually obtained with the most powerful accumulators.

A middle speed run has been obtained by Mr. Krebs, with a torpedo boat of 8·80m. He ran 6·4 knots on the Seine (real speed, accounting for that of the stream 11,852 meters per hour), with Reynier accumulators,* and 6·6 knots (12,223 m. per hour) at sea, with Commelin-Desmazures-Bailhache accumulators.† These speeds are remarkable, considering the small tonnage of the vessel and its heavy shape, which gives the coefficient an increased value.

* Experiments of the Concorde bridge, November 1866.

† Hâvre experiments, September 1887.

LAND ELECTRICAL LOCOMOTION.	ELECTRICAL NAVIGATION.
The useful exertion is independent of the speed.	The useful exertion is proportional to the square of the speed.
The useful power is proportional to the speed.	The useful power is proportional to the cube of the speed.
For a given journey, the expenditure of work is, theoretically, independent of the speed.	For a given run, the expenditure of work is, theoretically, proportional to the square of the speed.
A powerful battery is required to obtain a great speed.	An excessively powerful battery is required to obtain a great speed.
A good distance may be covered, whatever the gait, with the batteries actually known.	With the known batteries it is impossible to go far at a great speed. At small speed, on the contrary, long runs may be obtained.
A portion of the elevating works and of the live powers may be recuperated for recharging accumulators *en route*, the dynamo acting as a charger under the impulsion of the train in stiff inclines and sudden stoppages.	No recuperation.

The formulæ used in the calculation of P *u* and W *u*, the useful power and work, have been reported. In order to obtain the effective power and work P and W, P *u* and W *u* must be divided by the product of the two coefficients, which are:

d, mechanical transmission of the electric motor power to the propulser: $d = 0 \cdot 9$.

f, efficiency proper of the propulser. With good screws of comparatively large diameters $f = 0 \cdot 86$, so that

$$P = \frac{P\,u}{0 \cdot 774} \text{ and } W = \frac{W\,u}{0 \cdot 774}.$$

The efficiency of the accumulators, from the charging dynamo to its final utilisation is the product of five factors: *d* and *f*, and the three coefficients $a = 0 \cdot 85$, $b = 0 \cdot 72$, and $c = 0 \cdot 85$, common to all the mechanical applications of secondary couples.

We have therefore:

Practical efficiency of accumulators from the charging dynamo's pulley to the final utilisation.

$$= a \times b \times c \times d \times e \times f = 0 \cdot 40.$$

The coefficient *f*, it must be observed, appears in all the cases; so that the use of accumulators increases the expenditure of work only in the proportion,

$$\frac{1}{a \times b \times c \times d} = 2 \cdot 14.$$

That is to say, 2·14 horse-power must be expended at the works to obtain 1 horse-power on the propeller's shaft.

Future Application of Accumulators to Aerial Navigation.—Primary batteries have already been successfully used for the propulsion of aerostats. The accumulators will, as soon as their lightness shall become comparable to that of the lightest batteries, become very useful for this same purpose.

The weights of the lightest voltaic couples, primary and secondary, in function of 1 horse-power and 1 horse-power work per hour are given hereafter :

Couple.	Horse-power.	Horse-power hour.
	kilogrammes.	kilogrammes.
Gaston Tissandier—Amalgamated zinc-carbon, concentrated solution of bichromate of potash and sulphuric acid	75	30
C. Renard — Non-amalgamated zinc, platinum plated silver, chromic, chlorhydric, and sulphuric acids ..	36	18
Reynier's accumulator—Lead zinc	163	
Faure-Sellon-Volckmar accumulator—Experimental pattern	200	25·5
Commelin-Desmazures-Bailhache accumulator	170	37

The accumulators are left behind, especially when their weight is calculated in function of the power. But it may be hoped that they will one day be made to exceed in lightness even the lightest of primary batteries. In prevision of this fact we will give, hereafter, from Mr. C. Renard,* the expressions of the exertions and of the power required for the propulsion of elongated balloons, including the net and the car.

If we call :

D, the diameter of the balloon, in meters.
V, its speed, in meters per second.
F, the air resistance to the longitudinal motion of the apparatus.
P *u*, the useful power of traction.
P, the power on the propellor's shaft.

We shall have ;

$$F = 0{\cdot}01685\ D^2\ V^2 \text{ kilogramme.}$$

$$P\,u = 0{\cdot}01685\ D^2\ V^3 \text{ kilogrammeters per second.}$$

$$P = 0{\cdot}0326\ D^2\ V^3.$$

If we apply this last formula to a balloon of 10 meters diameter, which we want to propel at a speed proper of 10 meters per second, we find,

* "Sur les nouvelles expériences exécutées au moyen du ballon dirigeable, 'La France.'"—Note of Mr. C. Renard. 'Comptes Rendus de l'Académie des Sciences,' 7th December, 1885.

for the value of the power to produce on the propellor's shaft,

$$P = 0 \cdot 0326 \times \overline{10} \times \overline{10^3} = 3260 \text{ kgm. per second}$$
$$= 43 \cdot 5 \text{ H.P.}$$

Such a balloon could have a cube of 3140 m. and be directed in calm air or even in a moderately agitated atmosphere.

Transmission and Distribution of Energy by Means of Secondary Currents.—In a direct distribution of electric energy upon extended areas, the most costly item is the wiring. The redemption and maintenance of the conductors cripple the expenditure of exploitation. The transformers enable us to turn this difficulty. Primary currents of high tension, continuous or alternating, are used with long but thin conductors absorbing very little energy. At certain points of the circuit, these primary currents are made to pass through the transformators, where they induce secondary currents at the required potentials.

Accumulators would, in the distribution of electrical energy in large systems, render more complete services than transformators. They can, in effect, be distributed, like the transformators, where required, and give currents of the desired tension. Some special advantages result from their use.

1. The production and consumption are independent of each other; the consumer is not, therefore, subject to the irregularities or stoppages which may occur at the generating station.

2. The generating station, owing to this independence, may work regularly 20 hours out of 24, in spite of the variations in the consumption. The importance of the works being calculated according to the sum of energy required to be produced in a day, the plant and system of conductors are constantly utilised at full charge; whence a reduction of materials, and in the expenses of first establishment, maintenance, and redemption.

So that the accumulator which brings security to the concern is not an onerous auxiliary; the economies which it procures largely compensate for its first cost. Better known, it will become indispensable as the surest and most complete of transformers, as the best agent of distribution of electrical energy.*

* The efficiencies proper of induction transformers and of accumulators are respectively

Alternating current transformers ..	0·94
Continuous current transformers (according to regimens of work) ..	0·875 to 0·780
Accumulators	0·72

The alternating current transformers have the highest efficiency; but it distributes its energy under a form which allows only of its utilisation in calorific applications. The continuous current transformers are of a more general utilisation; their efficiency approaches that of accumulators, of which they do not always possess all the advantages.

Translation or Displacement of Energy.—The accumulators, precious auxiliaries of transmissions by conductors, enable the energy to be displaced without the help of a system of conductors. The process, which is disdained by some because it is so simple, consists in charging the accumulators near the motive-power, and transporting them, ready charged, to the spot where they are to be used.

Land-carriage of Energy.—It is the translation effected on land, on carriages, or on wagons. This method, in use for many years, will render great services when it is logically practised, with light accumulators.

Locomotion by accumulators gives us the spectacle of energy effecting its own translation, with an additional weight, which might consist of charged batteries travelling with their disposable energy.

Water-carriage of Energy.—It is the translation of energy on water. Floating is analogous to land carriage. It must, however, not be forgotten that *petite vitesse* water propulsion only requires a very feeble expenditure of work; if the accumulators are capable of vehiculating their own energy, they can carry it on water at a smaller sacrifice of the work embarked. It is therefore useful to mention this mode of translation of energy, not used yet to this day.

Caption of Natural Forces.—What has been said as regards the usefulness of accumulators for the transport and distribution of industrial forces, especially applies to natural forces.

In the case of a constant hydraulic power, the direct utilisation of it only takes place at the times of consumption, or 1500 hours (lighting) to 3000 or 3500 hours (mechanical uses). With accumulators, the force may be capted almost without interruption, that is to say for more than 8000 hours per annum.

When the force utilised is irregular, the direct process can only reckon its minimum power; the accumulators enable its average power to be utilised regularly or not.

Certain intermittent forces, such as wind, tides, &c., which are very little used, are easily exploitable by means of accumulators.

The caption of natural forces (actual energy) by means of secondary batteries, must gradually substitute itself to coal getting (fossil energy), which too exclusively supplies heat to our hearths and power to our engines.

400,000 miners are employed in coal fields. These may be considered as real battle-fields since 100,000 tons of coals cost, as an average, the life of one workman.*

Our sun, which caters to all the energies of

* E. Jouffret: 'Introduction à la Théorie de l'Énergie,' page 150.

nature, may also provide for all the artificial requirements of civilisation.

"Of the heat which this star sheds in every direction, the earth, which is for it a small disc subtending an arc of 17 seconds,* only intercepts a fraction equal to unity divided by a number exceeding two milliards. This particle, however, is equivalent to the sum of heat which could be obtained by burning, daily, 500,000,000 tons of coals, or an amount equal to about 2000 times the annual production of all the coal-fields of the globe. It is this particle which constitutes life on our planet; the movements existing in its atmosphere or at its surface, the vegetable and animal existences, the battles which we sustain to increase our comfort or to inter-destroy one another, &c., are but effects, utilisations or abuses of it.

"Very few indeed are the cases where energy comes from other sources. We can mention—Volcanic eruptions and earthquakes, due to central heat and pressure; the motion of tides, the energy of which has its source in the diurnal rotation; so that, if we succeeded in utilising on a large scale the force which exists in the influx and reflux, by means of turbines or otherwise, this

* "This angle is 110 times smaller than that under which we see the moon, and half of that under which the planet Venus appears to us when seen at its most brilliant periods. It is equal to that under which we should perceive a billiard ball (0·06 m.) placed at a distance of 700 meters from our eye."

rotation would be seen to slack and the day grow longer.*

It is unreasonable to fear the fatal exhaustion of coal-fields ; they will be abandoned much before being exhausted.

"The Niagara Falls only, where 100,000,000 tons of water fall, per hour, from a height of 47 meters, represent as much energy as is actually consumed upon the whole surface of the earth."†

The abandonment of coal-fields, rendered possible by the use of the voltaic accumulator, will bring an industrial revolution the social consequences of which can already be perceived.

Without insisting upon these considerations, the author is in the hope of having shown how vast is, by its consequences, the object of this small *Treatise*.

* Jouffret : *Loc. cit.*, pp. 131 and 132.
† *Loc. cit.*, 151.

LONDON: PRINTED BY WILLIAM CLOWES AND SONS, LIMITED,
STAMFORD STREET AND CHARING CROSS.

1888.

BOOKS RELATING

TO

APPLIED SCIENCE,

PUBLISHED BY

E. & F. N. SPON,

LONDON: 125, STRAND.

NEW YORK: 12, CORTLANDT STREET.

A Pocket-Book for Chemists, Chemical Manufacturers, Metallurgists, Dyers, Distillers, Brewers, Sugar Refiners, Photographers, Students, etc., etc. By THOMAS BAYLEY, Assoc. R.C. Sc. Ireland, Analytical and Consulting Chemist and Assayer. Fourth edition, with additions, 437 pp., royal 32mo, roan, gilt edges, 5*s.*

SYNOPSIS OF CONTENTS:

Atomic Weights and Factors—Useful Data—Chemical Calculations—Rules for Indirect Analysis—Weights and Measures—Thermometers and Barometers—Chemical Physics—Boiling Points, etc.—Solubility of Substances—Methods of Obtaining Specific Gravity—Conversion of Hydrometers—Strength of Solutions by Specific Gravity—Analysis—Gas Analysis—Water Analysis—Qualitative Analysis and Reactions—Volumetric Analysis—Manipulation—Mineralogy—Assaying—Alcohol—Beer—Sugar—Miscellaneous Technological matter relating to Potash, Soda, Sulphuric Acid, Chlorine, Tar Products, Petroleum, Milk, Tallow, Photography, Prices, Wages, Appendix, etc., etc.

The Mechanician: A Treatise on the Construction and Manipulation of Tools, for the use and instruction of Young Engineers and Scientific Amateurs, comprising the Arts of Blacksmithing and Forging; the Construction and Manufacture of Hand Tools, and the various Methods of Using and Grinding them; the Construction of Machine Tools, and how to work them; Machine Fitting and Erection; description of Hand and Machine Processes; Turning and Screw Cutting; principles of Constructing and details of Making and Erecting Steam Engines, and the various details of setting out work, etc., etc. By CAMERON KNIGHT, Engineer. *Containing* 1147 *illustrations*, and 397 pages of letter-press, Fourth edition, 4to, cloth, 18*s.*

Just Published, in Demy 8vo, cloth, containing 975 pages and 250 Illustrations, price 7s. 6d.

SPONS' HOUSEHOLD MANUAL:

A Treasury of Domestic Receipts and Guide for Home Management.

PRINCIPAL CONTENTS.

Hints for selecting a good House, pointing out the essential requirements for a good house as to the Site, Soil, Trees, Aspect, Construction, and General Arrangement; with instructions for Reducing Echoes, Waterproofing Damp Walls, Curing Damp Cellars.

Sanitation.—What should constitute a good Sanitary Arrangement; Examples (with illustrations) of Well- and Ill-drained Houses; How to Test Drains; Ventilating Pipes, etc.

Water Supply.—Care of Cisterns; Sources of Supply; Pipes; Pumps; Purification and Filtration of Water.

Ventilation and Warming.—Methods of Ventilating without causing cold draughts, by various means; Principles of Warming; Health Questions; Combustion; Open Grates; Open Stoves; Fuel Economisers; Varieties of Grates; Close-Fire Stoves; Hot-air Furnaces; Gas Heating; Oil Stoves; Steam Heating; Chemical Heaters; Management of Flues; and Cure of Smoky Chimneys.

Lighting.—The best methods of Lighting; Candles, Oil Lamps, Gas, Incandescent Gas, Electric Light; How to test Gas Pipes; Management of Gas.

Furniture and Decoration.—Hints on the Selection of Furniture; on the most approved methods of Modern Decoration; on the best methods of arranging Bells and Calls; How to Construct an Electric Bell.

Thieves and Fire.—Precautions against Thieves and Fire; Methods of Detection; Domestic Fire Escapes; Fireproofing Clothes, etc.

The Larder.—Keeping Food fresh for a limited time; Storing Food without change, such as Fruits, Vegetables, Eggs, Honey, etc.

Curing Foods for lengthened Preservation, as Smoking, Salting, Canning, Potting, Pickling, Bottling Fruits, etc.; Jams, Jellies, Marmalade, etc.

The Dairy.—The Building and Fitting of Dairies in the most approved modern style; Butter-making; Cheesemaking and Curing.

The Cellar.—Building and Fitting; Cleaning Casks and Bottles; Corks and Corking; Aërated Drinks; Syrups for Drinks; Beers; Bitters; Cordials and Liqueurs; Wines; Miscellaneous Drinks.

The Pantry.—Bread-making; Ovens and Pyrometers; Yeast; German Yeast; Biscuits; Cakes; Fancy Breads; Buns.

The Kitchen.—On Fitting Kitchens; a description of the best Cooking Ranges, close and open; the Management and Care of Hot Plates, Baking Ovens, Dampers, Flues, and Chimneys; Cooking by Gas; Cooking by Oil; the Arts of Roasting, Grilling, Boiling, Stewing, Braising, Frying.

Receipts for Dishes—Soups, Fish, Meat, Game, Poultry, Vegetables, Salads, Puddings, Pastry, Confectionery, Ices, etc., etc.; Foreign Dishes.

The Housewife's Room.—Testing Air, Water, and Foods; Cleaning and Renovating; Destroying Vermin.

Housekeeping, Marketing.

The Dining-Room.—Dietetics; Laying and Waiting at Table; Carving; Dinners, Breakfasts, Luncheons, Teas, Suppers, etc.

The Drawing-Room.—Etiquette; Dancing; Amateur Theatricals; Tricks and Illusions; Games (indoor).

The Bedroom and Dressing-Room; Sleep; the Toilet; Dress; Buying Clothes; Outfits; Fancy Dress.

The Nursery.—The Room; Clothing; Washing; Exercise; Sleep; Feeding; Teething; Illness; Home Training.

The Sick-Room.—The Room; the Nurse; the Bed; Sick Room Accessories; Feeding Patients; Invalid Dishes and Drinks; Administering Physic; Domestic Remedies; Accidents and Emergencies; Bandaging; Burns; Carrying Injured Persons; Wounds; Drowning; Fits; Frost-bites; Poisons and Antidotes; Sunstroke; Common Complaints; Disinfection, etc.

The Bath-Room.—Bathing in General; Management of Hot-Water System.

The Laundry.—Small Domestic Washing Machines, and methods of getting up linen; Fitting up and Working a Steam Laundry.

The School-Room.—The Room and its Fittings; Teaching, etc.

The Playground.—Air and Exercise; Training; Outdoor Games and Sports.

The Workroom.—Darning, Patching, and Mending Garments.

The Library.—Care of Books.

The Garden.—Calendar of Operations for Lawn, Flower Garden, and Kitchen Garden.

The Farmyard.—Management of the Horse, Cow, Pig, Poultry, Bees, etc., etc.

Small Motors.—A description of the various small Engines useful for domestic purposes, from 1 man to 1 horse power, worked by various methods, such as Electric Engines, Gas Engines, Petroleum Engines, Steam Engines, Condensing Engines, Water Power, Wind Power, and the various methods of working and managing them.

Household Law.—The Law relating to Landlords and Tenants, Lodgers, Servants, Parochial Authorities, Juries, Insurance, Nuisance, etc.

On Designing Belt Gearing. By E. J. COWLING WELCH, Mem. Inst. Mech. Engineers, Author of 'Designing Valve Gearing.' Fcap. 8vo, sewed, 6*d.*

A Handbook of Formulæ, Tables, and Memoranda, for Architectural Surveyors and others engaged in Building. By J. T. HURST, C.E. Fourteenth edition, royal 32mo, roan, 5*s.*

"It is no disparagement to the many excellent publications we refer to, to say that in our opinion this little pocket-book of Hurst's is the very best of them all, without any exception. It would be useless to attempt a recapitulation of the contents, for it appears to contain almost *everything* that anyone connected with building could require, and, best of all, made up in a compact form for carrying in the pocket, measuring only 5 in. by 3 in., and about ¾ in. thick, in a limp cover. We congratulate the author on the success of his laborious and practically compiled little book, which has received unqualified and deserved praise from every professional person to whom we have shown it."—*The Dublin Builder.*

Tabulated Weights of Angle, Tee, Bulb, Round, Square, and Flat Iron and Steel, and other information for the use of Naval Architects and Shipbuilders. By C. H. JORDAN, M.I.N.A. Fourth edition, 32mo, cloth, 2*s.* 6*d.*

A Complete Set of Contract Documents for a Country Lodge, comprising Drawings, Specifications, Dimensions (for quantities), Abstracts, Bill of Quantities, Form of Tender and Contract, with Notes by J. LEANING, printed in facsimile of the original documents, on single sheets fcap., in paper case, 10*s.*

A Practical Treatise on Heat, as applied to the Useful Arts; for the Use of Engineers, Architects, &c. By THOMAS BOX. *With* 14 *plates.* Third edition, crown 8vo, cloth, 12*s.* 6*d.*

A Descriptive Treatise on Mathematical Drawing Instruments: their construction, uses, qualities, selection, preservation, and suggestions for improvements, with hints upon Drawing and Colouring. By W. F. STANLEY, M.R.I. Fifth edition, *with numerous illustrations,* crown 8vo, cloth, 5*s.*

Quantity Surveying. By J. LEANING. With 42 illustrations. Second edition, revised, crown 8vo, cloth, 9*s.*

CONTENTS :

A complete Explanation of the London Practice.
General Instructions.
Order of Taking Off.
Modes of Measurement of the various Trades.
Use and Waste.
Ventilation and Warming.
Credits, with various Examples of Treatment.
Abbreviations.
Squaring the Dimensions.
Abstracting, with Examples in illustration of each Trade.
Billing.
Examples of Preambles to each Trade.
Form for a Bill of Quantities.
Do. Bill of Credits.
Do. Bill for Alternative Estimate.
Restorations and Repairs, and Form of Bill.
Variations before Acceptance of Tender.
Errors in a Builder's Estimate.
Schedule of Prices.
Form of Schedule of Prices.
Analysis of Schedule of Prices.
Adjustment of Accounts.
Form of a Bill of Variations.
Remarks on Specifications.
Prices and Valuation of Work, with Examples and Remarks upon each Trade.
The Law as it affects Quantity Surveyors, with Law Reports.
Taking Off after the Old Method.
Northern Practice.
The General Statement of the Methods recommended by the Manchester Society of Architects for taking Quantities.
Examples of Collections.
Examples of "Taking Off" in each Trade.
Remarks on the Past and Present Methods of Estimating.

Spons' Architects' and Builders' Price Book, with useful Memoranda. Edited by W. YOUNG, Architect. Crown 8vo, cloth, red edges, 3*s.* 6*d.* *Published annually.* Sixteenth edition. *Now ready.*

Long-Span Railway Bridges, comprising Investigations of the Comparative Theoretical and Practical Advantages of the various adopted or proposed Type Systems of Construction, with numerous Formulæ and Tables giving the weight of Iron or Steel required in Bridges from 300 feet to the limiting Spans; to which are added similar Investigations and Tables relating to Short-span Railway Bridges. Second and revised edition. By B. BAKER, Assoc. Inst. C.E. *Plates*, crown 8vo, cloth, 5*s.*

Elementary Theory and Calculation of Iron Bridges and Roofs. By AUGUST RITTER, Ph.D., Professor at the Polytechnic School at Aix-la-Chapelle. Translated from the third German edition, by H. R. SANKEY, Capt. R.E. With 500 *illustrations*, 8vo, cloth, 15*s.*

The Elementary Principles of Carpentry. By THOMAS TREDGOLD. Revised from the original edition, and partly re-written, by JOHN THOMAS HURST. Contained in 517 pages of letterpress, and *illustrated with* 48 *plates and* 150 *wood engravings.* Sixth edition, reprinted from the third, crown 8vo, cloth, 12*s.* 6*d.*

Section I. On the Equality and Distribution of Forces — Section II. Resistance of Timber — Section III. Construction of Floors — Section IV. Construction of Roofs — Section V. Construction of Domes and Cupolas — Section VI. Construction of Partitions — Section VII. Scaffolds, Staging, and Gantries — Section VIII. Construction of Centres for Bridges — Section IX. Coffer-dams, Shoring, and Strutting — Section X. Wooden Bridges and Viaducts — Section XI. Joints, Straps, and other Fastenings — Section XII. Timber.

The Builder's Clerk: a Guide to the Management of a Builder's Business. By THOMAS BALES. Fcap. 8vo, cloth, 1*s.* 6*d.*

Our Factories, Workshops, and Warehouses: their Sanitary and Fire-Resisting Arrangements. By B. H. THWAITE, Assoc. Mem. Inst. C.E. *With* 183 *wood engravings*, crown 8vo, cloth, 9*s.*

Gold: Its Occurrence and Extraction, embracing the Geographical and Geological Distribution and the Mineralogical Characters of Gold-bearing rocks; the peculiar features and modes of working Shallow Placers, Rivers, and Deep Leads; Hydraulicing; the Reduction and Separation of Auriferous Quartz; the treatment of complex Auriferous ores containing other metals; a Bibliography of the subject and a Glossary of Technical and Foreign Terms. By ALFRED G. LOCK, F.R.G.S. *With numerous illustrations and maps*, 1250 pp., super-royal 8vo, cloth, 2*l.* 12*s.* 6*d.*

Iron Roofs: Examples of Design, Description. *Illustrated with* 64 *Working Drawings of Executed Roofs.* By ARTHUR T. WALMISLEY, Assoc. Mem. Inst. C.E. Second edition, revised, imp. 4to, half-morocco, 3*l.* 3*s.*

A History of Electric Telegraphy, to the Year 1837. Chiefly compiled from Original Sources, and hitherto Unpublished Documents, by J. J. FAHIE, Mem. Soc. of Tel. Engineers, and of the International Society of Electricians, Paris. Crown 8vo, cloth, 9*s.*

Spons' Information for Colonial Engineers. Edited by J. T. HURST. Demy 8vo, sewed.

No. 1, Ceylon. By ABRAHAM DEANE, C.E. 2*s.* 6*d.*

CONTENTS:

Introductory Remarks—Natural Productions—Architecture and Engineering—Topography, Trade, and Natural History—Principal Stations—Weights and Measures, etc., etc.

No. 2. Southern Africa, including the Cape Colony, Natal, and the Dutch Republics. By HENRY HALL, F.R.G.S., F.R.C.I. With Map. 3*s.* 6*d.*

CONTENTS:

General Description of South Africa—Physical Geography with reference to Engineering Operations—Notes on Labour and Material in Cape Colony—Geological Notes on Rock Formation in South Africa—Engineering Instruments for Use in South Africa—Principal Public Works in Cape Colony: Railways, Mountain Roads and Passes, Harbour Works, Bridges, Gas Works, Irrigation and Water Supply, Lighthouses, Drainage and Sanitary Engineering, Public Buildings, Mines—Table of Woods in South Africa—Animals used for Draught Purposes—Statistical Notes—Table of Distances—Rates of Carriage, etc.

No. 3. India. By F. C. DANVERS, Assoc. Inst. C.E. With Map. 4*s.* 6*d.*

CONTENTS:

Physical Geography of India—Building Materials—Roads—Railways—Bridges—Irrigation—River Works—Harbours—Lighthouse Buildings—Native Labour—The Principal Trees of India—Money—Weights and Measures—Glossary of Indian Terms, etc.

A Practical Treatise on Coal Mining. By GEORGE G. ANDRÉ, F.G.S., Assoc. Inst. C.E., Member of the Society of Engineers. *With* 82 *lithographic plates.* 2 vols., royal 4to, cloth, 3*l.* 12*s.*

A Practical Treatise on Casting and Founding, including descriptions of the modern machinery employed in the art. By N. E. SPRETSON, Engineer. Third edition, with 82 *plates* drawn to scale, 412 pp., demy 8vo, cloth, 18*s.*

The Depreciation of Factories and their Valuation. By EWING MATHESON, M. Inst. C.E. 8vo, cloth, 6*s.*

A Handbook of Electrical Testing. By H. R. KEMPE, M.S.T.E. Fourth edition, revised and enlarged, crown 8vo, cloth, 16*s.*

Gas Works: their Arrangement, Construction, Plant, and Machinery. By F. COLYER, M. Inst. C.E. *With* 31 *folding plates,* 8vo, cloth, 24*s.*

The Clerk of Works: a Vade-Mecum for all engaged in the Superintendence of Building Operations. By G. G. HOSKINS, F.R.I.B.A. Third edition, fcap. 8vo, cloth, 1*s.* 6*d.*

American Foundry Practice: Treating of Loam, Dry Sand, and Green Sand Moulding, and containing a Practical Treatise upon the Management of Cupolas, and the Melting of Iron. By T. D. WEST, Practical Iron Moulder and Foundry Foreman. Second edition, *with numerous illustrations,* crown 8vo, cloth, 10*s.* 6*d.*

The Maintenance of Macadamised Roads. By T. CODRINGTON, M.I.C.E, F.G.S., General Superintendent of County Roads for South Wales. 8vo, cloth, 6*s.*

Hydraulic Steam and Hand Power Lifting and Pressing Machinery. By FREDERICK COLYER, M. Inst. C.E., M. Inst. M.E. *With* 73 *plates,* 8vo, cloth, 18*s.*

Pumps and Pumping Machinery. By F. COLYER, M.I.C.E., M.I.M.E. *With* 23 *folding plates,* 8vo, cloth, 12*s.* 6*d.*

Pumps and Pumping Machinery. By F. COLYER. Second Part. *With* 11 *large plates,* 8vo, cloth, 12*s.* 6*d.*

A Treatise on the Origin, Progress, Prevention, and Cure of Dry Rot in Timber; with Remarks on the Means of Preserving Wood from Destruction by Sea-Worms, Beetles, Ants, etc. By THOMAS ALLEN BRITTON, late Surveyor to the Metropolitan Board of Works, etc., etc. *With* 10 *plates,* crown 8vo, cloth, 7*s.* 6*d.*

The Municipal and Sanitary Engineer's Handbook. By H. PERCY BOULNOIS, Mem. Inst. C.E., Borough Engineer, Portsmouth. *With numerous illustrations*, demy 8vo, cloth, 12*s*. 6*d*.

CONTENTS:

The Appointment and Duties of the Town Surveyor—Traffic—Macadamised Roadways—Steam Rolling—Road Metal and Breaking—Pitched Pavements—Asphalte—Wood Pavements—Footpaths—Kerbs and Gutters—Street Naming and Numbering—Street Lighting—Sewerage—Ventilation of Sewers—Disposal of Sewage—House Drainage—Disinfection—Gas and Water Companies, etc., Breaking up Streets—Improvement of Private Streets—Borrowing Powers—Artizans' and Labourers' Dwellings—Public Conveniences—Scavenging, including Street Cleansing—Watering and the Removing of Snow—Planting Street Trees—Deposit of Plans—Dangerous Buildings—Hoardings—Obstructions—Improving Street Lines—Cellar Openings—Public Pleasure Grounds—Cemeteries—Mortuaries—Cattle and Ordinary Markets—Public Slaughter-houses, etc.—Giving numerous Forms of Notices, Specifications, and General Information upon these and other subjects of great importance to Municipal Engineers and others engaged in Sanitary Work.

Metrical Tables. By G. L. MOLESWORTH, M.I.C.E. 32mo, cloth, 1*s*. 6*d*.

CONTENTS.

General—Linear Measures—Square Measures—Cubic Measures—Measures of Capacity—Weights—Combinations—Thermometers.

Elements of Construction for Electro-Magnets. By Count TH. DU MONCEL, Mem. de l'Institut de France. Translated from the French by C. J. WHARTON. Crown 8vo, cloth, 4*s*. 6*d*.

Practical Electrical Units Popularly Explained, with *numerous illustrations* and Remarks. By JAMES SWINBURNE, late of J. W. Swan and Co., Paris, late of Brush-Swan Electric Light Company, U.S.A. 18mo, cloth, 1*s*. 6*d*.

A Treatise on the Use of Belting for the Transmission of Power. By J. H. COOPER. Second edition, *illustrated*, 8vo, cloth, 15*s*.

A Pocket-Book of Useful Formulæ and Memoranda for Civil and Mechanical Engineers. By GUILFORD L. MOLESWORTH, Mem. Inst. C.E., Consulting Engineer to the Government of India for State Railways. *With numerous illustrations*, 744 pp. Twenty-second edition, revised and enlarged, 32mo, roan, 6*s*.

SYNOPSIS OF CONTENTS:

Surveying, Levelling, etc.—Strength and Weight of Materials—Earthwork, Brickwork, Masonry, Arches, etc.—Struts, Columns, Beams, and Trusses—Flooring, Roofing, and Roof Trusses—Girders, Bridges, etc.—Railways and Roads—Hydraulic Formulæ—Canals, Sewers, Waterworks, Docks—Irrigation and Breakwaters—Gas, Ventilation, and Warming—Heat, Light, Colour, and Sound—Gravity: Centres, Forces, and Powers—Millwork, Teeth of Wheels, Shafting, etc.—Workshop Recipes—Sundry Machinery—Animal Power—Steam and the Steam Engine—Water-power, Water-wheels, Turbines, etc.—Wind and Windmills—Steam Navigation, Ship Building, Tonnage, etc.—Gunnery, Projectiles, etc.—Weights, Measures, and Money—Trigonometry, Conic Sections, and Curves—Telegraphy—Mensuration—Tables of Areas and Circumference, and Arcs of Circles—Logarithms, Square and Cube Roots, Powers—Reciprocals, etc.—Useful Numbers—Differential and Integral Calculus—Algebraic Signs—Telegraphic Construction and Formulæ.

Hints on Architectural Draughtsmanship. By G. W. Tuxford Hallatt. Fcap. 8vo, cloth, 1*s*. 6*d*.

Spons' Tables and Memoranda for Engineers; selected and arranged by J. T. Hurst, C.E., Author of 'Architectural Surveyors' Handbook,' 'Hurst's Tredgold's Carpentry,' etc. Ninth edition, 64mo, roan, gilt edges, 1*s*.; or in cloth case, 1*s*. 6*d*.

This work is printed in a pearl type, and is so small, measuring only $2\frac{1}{2}$ in. by $1\frac{3}{4}$ in. by $\frac{1}{4}$ in. thick, that it may be easily carried in the waistcoat pocket.

"It is certainly an extremely rare thing for a reviewer to be called upon to notice a volume measuring but $2\frac{1}{2}$ in. by $1\frac{3}{4}$ in., yet these dimensions faithfully represent the size of the handy little book before us. The volume—which contains 118 printed pages, besides a few blank pages for memoranda—is, in fact, a true pocket-book, adapted for being carried in the waistcoat pocket, and containing a far greater amount and variety of information than most people would imagine could be compressed into so small a space. . . . . The little volume has been compiled with considerable care and judgment, and we can cordially recommend it to our readers as a useful little pocket companion."—*Engineering.*

A Practical Treatise on Natural and Artificial Concrete, its Varieties and Constructive Adaptations. By Henry Reid, Author of the 'Science and Art of the Manufacture of Portland Cement.' New Edition, *with* 59 *woodcuts and* 5 *plates*, 8vo, cloth, 15*s*.

Notes on Concrete and Works in Concrete; especially written to assist those engaged upon Public Works. By John Newman, Assoc. Mem. Inst. C.E., crown 8vo, cloth, 4*s*. 6*d*.

Electricity as a Motive Power. By Count Th. Du Moncel, Membre de l'Institut de France, and Frank Geraldy, Ingénieur des Ponts et Chaussées. Translated and Edited, with Additions, by C. J. Wharton, Assoc. Soc. Tel. Eng. and Elec. *With* 113 *engravings and diagrams*, crown 8vo, cloth, 7*s*. 6*d*.

Treatise on Valve-Gears, with special consideration of the Link-Motions of Locomotive Engines. By Dr. Gustav Zeuner, Professor of Applied Mechanics at the Confederated Polytechnikum of Zurich. Translated from the Fourth German Edition, by Professor J. F. Klein, Lehigh University, Bethlehem, Pa. *Illustrated*, 8vo, cloth, 12*s*. 6*d*.

The French-Polisher's Manual. By a French-Polisher; containing Timber Staining, Washing, Matching, Improving, Painting, Imitations, Directions for Staining, Sizing, Embodying, Smoothing, Spirit Varnishing, French-Polishing, Directions for Re-polishing. Third edition, royal 32mo, sewed, 6*d*.

Hops, their Cultivation, Commerce, and Uses in various Countries. By P. L. Simmonds. Crown 8vo, cloth, 4*s*. 6*d*.

The Principles of Graphic Statics. By George Sydenham Clarke, Capt. Royal Engineers. *With* 112 *illustrations.* 4to, cloth, 12*s*. 6*d*.

Dynamo-Electric Machinery: A Manual for Students of Electro-technics. By SILVANUS P. THOMPSON, B.A., D.Sc., Professor of Experimental Physics in University College, Bristol, etc., etc. Third edition, *illustrated*, 8vo, cloth, 16*s*.

Practical Geometry, Perspective, and Engineering Drawing; a Course of Descriptive Geometry adapted to the Requirements of the Engineering Draughtsman, including the determination of cast shadows and Isometric Projection, each chapter being followed by numerous examples; to which are added rules for Shading, Shade-lining, etc., together with practical instructions as to the Lining, Colouring, Printing, and general treatment of Engineering Drawings, with a chapter on drawing Instruments. By GEORGE S. CLARKE, Capt. R.E. Second edition, *with* 21 *plates*. 2 vols., cloth, 10*s*. 6*d*.

The Elements of Graphic Statics. By Professor KARL VON OTT, translated from the German by G. S. CLARKE, Capt. R.E., Instructor in Mechanical Drawing, Royal Indian Engineering College. *With* 93 *illustrations*, crown 8vo, cloth, 5*s*.

A Practical Treatise on the Manufacture and Distribution of Coal Gas. By WILLIAM RICHARDS. Demy 4to, with *numerous wood engravings and* 29 *plates*, cloth, 28*s*.

SYNOPSIS OF CONTENTS:

Introduction—History of Gas Lighting—Chemistry of Gas Manufacture, by Lewis Thompson, Esq., M.R.C.S.—Coal, with Analyses, by J. Paterson, Lewis Thompson, and G. R. Hislop, Esqrs.—Retorts, Iron and Clay—Retort Setting—Hydraulic Main—Condensers—Exhausters—Washers and Scrubbers—Purifiers—Purification—History of Gas Holder—Tanks, Brick and Stone, Composite, Concrete, Cast-iron, Compound Annular Wrought-iron—Specifications—Gas Holders—Station Meter—Governor—Distribution—Mains—Gas Mathematics, or Formulæ for the Distribution of Gas, by Lewis Thompson, Esq.—Services—Consumers' Meters—Regulators—Burners—Fittings—Photometer—Carburization of Gas—Air Gas and Water Gas—Composition of Coal Gas, by Lewis Thompson, Esq.—Analyses of Gas—Influence of Atmospheric Pressure and Temperature on Gas—Residual Products—Appendix—Description of Retort Settings, Buildings, etc., etc.

The New Formula for Mean Velocity of Discharge of Rivers and Canals. By W. R. KUTTER. Translated from articles in the 'Cultur-Ingénieur,' by LOWIS D'A. JACKSON, Assoc. Inst. C.E. 8vo, cloth, 12*s*. 6*d*.

The Practical Millwright and Engineer's Ready Reckoner; or Tables for finding the diameter and power of cog-wheels, diameter, weight, and power of shafts, diameter and strength of bolts, etc. By THOMAS DIXON. Fourth edition, 12mo, cloth, 3*s*.

Tin: Describing the Chief Methods of Mining, Dressing and Smelting it abroad; with Notes upon Arsenic, Bismuth and Wolfram. By ARTHUR G. CHARLETON, Mem. American Inst. of Mining Engineers. *With plates*, 8vo, cloth, 12*s*. 6*d*.

Perspective, Explained and Illustrated. By G. S. Clarke, Capt. R.E. *With illustrations*, 8vo, cloth, 3*s.* 6*d.*

Practical Hydraulics; a Series of Rules and Tables for the use of Engineers, etc., etc. By Thomas Box. Fifth edition, *numerous plates*, post 8vo, cloth, 5*s.*

The Essential Elements of Practical Mechanics; based on the Principle of Work, designed for Engineering Students. By Oliver Byrne, formerly Professor of Mathematics, College for Civil Engineers. Third edition, *with* 148 *wood engravings*, post 8vo, cloth, 7*s.* 6*d.*

Contents:

Chap. 1. How Work is Measured by a Unit, both with and without reference to a Unit of Time—Chap. 2. The Work of Living Agents, the Influence of Friction, and introduces one of the most beautiful Laws of Motion—Chap. 3. The principles expounded in the first and second chapters are applied to the Motion of Bodies—Chap. 4. The Transmission of Work by simple Machines—Chap. 5. Useful Propositions and Rules.

Breweries and Maltings: their Arrangement, Construction, Machinery, and Plant. By G. Scamell, F.R.I.B.A. Second edition, revised, enlarged, and partly rewritten. By F. Colyer, M.I.C.E., M.I.M.E. *With* 20 *plates*, 8vo, cloth, 18*s.*

A Practical Treatise on the Construction of Horizontal and Vertical Waterwheels, specially designed for the use of operative mechanics. By William Cullen, Millwright and Engineer. *With* 11 *plates.* Second edition, revised and enlarged, small 4to, cloth, 12*s.* 6*d.*

A Practical Treatise on Mill-gearing, Wheels, Shafts, Riggers, etc.; for the use of Engineers. By Thomas Box. Third edition, *with* 11 *plates.* Crown 8vo, cloth, 7*s.* 6*d.*

Mining Machinery: a Descriptive Treatise on the Machinery, Tools, and other Appliances used in Mining. By G. G. André, F.G.S., Assoc. Inst. C.E., Mem. of the Society of Engineers. Royal 4to, uniform with the Author's Treatise on Coal Mining, containing 182 *plates*, accurately drawn to scale, with descriptive text, in 2 vols., cloth, 3*l.* 12*s.*

Contents:

Machinery for Prospecting, Excavating, Hauling, and Hoisting—Ventilation—Pumping—Treatment of Mineral Products, including Gold and Silver, Copper, Tin, and Lead, Iron Coal, Sulphur, China Clay, Brick Earth, etc.

Tables for Setting out Curves for Railways, Canals, Roads, etc., varying from a radius of five chains to three miles. By A. Kennedy and R. W. Hackwood. *Illustrated*, 32mo, cloth, 2*s.* 6*d.*

The Science and Art of the Manufacture of Portland Cement, with observations on some of its constructive applications. *With 66 illustrations.* By HENRY REID, C.E., Author of 'A Practical Treatise on Concrete,' etc., etc. 8vo, cloth, 18*s*.

The Draughtsman's Handbook of Plan and Map Drawing; including instructions for the preparation of Engineering, Architectural, and Mechanical Drawings. *With numerous illustrations in the text, and 33 plates (15 printed in colours).* By G. G. ANDRÉ, F.G.S., Assoc. Inst. C.E. 4to, cloth, 9*s*.

CONTENTS:

The Drawing Office and its Furnishings—Geometrical Problems—Lines, Dots, and their Combinations—Colours, Shading, Lettering, Bordering, and North Points—Scales—Plotting—Civil Engineers' and Surveyors' Plans—Map Drawing—Mechanical and Architectural Drawing—Copying and Reducing Trigonometrical Formulæ, etc., etc.

The Boiler-maker's and Iron Ship-builder's Companion, comprising a series of original and carefully calculated tables, of the utmost utility to persons interested in the iron trades. By JAMES FODEN, author of 'Mechanical Tables,' etc. Second edition revised, *with illustrations*, crown 8vo, cloth, 5*s*.

Rock Blasting: a Practical Treatise on the means employed in Blasting Rocks for Industrial Purposes. By G. G. ANDRÉ, F.G.S., Assoc. Inst. C.E. *With 56 illustrations and 12 plates*, 8vo, cloth, 10*s*. 6*d*.

Painting and Painters' Manual: a Book of Facts for Painters and those who Use or Deal in Paint Materials. By C. L. CONDIT and J. SCHELLER. *Illustrated*, 8vo, cloth, 10*s*. 6*d*.

A Treatise on Ropemaking as practised in public and private Rope-yards, with a Description of the Manufacture, Rules, Tables of Weights, etc., adapted to the Trade, Shipping, Mining, Railways, Builders, etc. By R. CHAPMAN, formerly foreman to Messrs. Huddart and Co., Limehouse, and late Master Ropemaker to H.M. Dockyard, Deptford. Second edition, 12mo, cloth, 3*s*.

Laxton's Builders' and Contractors' Tables; for the use of Engineers, Architects, Surveyors, Builders, Land Agents, and others. Bricklayer, containing 22 tables, with nearly 30,000 calculations. 4to, cloth, 5*s*.

Laxton's Builders' and Contractors' Tables. Excavator, Earth, Land, Water, and Gas, containing 53 tables, with nearly 24,000 calculations. 4to, cloth, 5*s*.

Sanitary Engineering: a Guide to the Construction of Works of Sewerage and House Drainage, with Tables for facilitating the calculations of the Engineer. By BALDWIN LATHAM, C.E., M. Inst. C.E., F.G.S., F.M.S., Past-President of the Society of Engineers. Second edition, *with numerous plates and woodcuts*, 8vo, cloth, 1*l.* 10*s.*

Screw Cutting Tables for Engineers and Machinists, giving the values of the different trains of Wheels required to produce Screws of any pitch, calculated by Lord Lindsay, M.P., F.R.S., F.R.A.S., etc. Cloth, oblong, 2*s.*

Screw Cutting Tables, for the use of Mechanical Engineers, showing the proper arrangement of Wheels for cutting the Threads of Screws of any required pitch, with a Table for making the Universal Gas-pipe Threads and Taps. By W. A. MARTIN, Engineer. Second edition, oblong, cloth, 1*s.*, or sewed, 6*d.*

A Treatise on a Practical Method of Designing Slide-Valve Gears by Simple Geometrical Construction, based upon the principles enunciated in Euclid's Elements, and comprising the various forms of Plain Slide-Valve and Expansion Gearing; together with Stephenson's, Gooch's, and Allan's Link-Motions, as applied either to reversing or to variable expansion combinations. By EDWARD J. COWLING WELCH, Memb. Inst. Mechanical Engineers. Crown 8vo, cloth, 6*s.*

Cleaning and Scouring: a Manual for Dyers, Laundresses, and for Domestic Use. By S. CHRISTOPHER. 18mo, sewed, 6*d.*

A Glossary of Terms used in Coal Mining. By WILLIAM STUKELEY GRESLEY, Assoc. Mem. Inst. C.E., F.G.S., Member of the North of England Institute of Mining Engineers. *Illustrated with numerous woodcuts and diagrams*, crown 8vo, cloth, 5*s.*

A Pocket-Book for Boiler Makers and Steam Users, comprising a variety of useful information for Employer and Workman, Government Inspectors, Board of Trade Surveyors, Engineers in charge of Works and Slips, Foremen of Manufactories, and the general Steam-using Public. By MAURICE JOHN SEXTON. Second edition, royal 32mo, roan, gilt edges, 5*s.*

Electrolysis: a Practical Treatise on Nickeling, Coppering, Gilding, Silvering, the Refining of Metals, and the treatment of Ores by means of Electricity. By HIPPOLYTE FONTAINE, translated from the French by J. A. BERLY, C.E., Assoc. S.T.E. *With engravings.* 8vo, cloth, 9*s.*

Barlow's Tables of Squares, Cubes, Square Roots, Cube Roots, Reciprocals of all Integer Numbers up to 10,000. Post 8vo, cloth, 6*s.*

A Practical Treatise on the Steam Engine, containing Plans and Arrangements of Details for Fixed Steam Engines, with Essays on the Principles involved in Design and Construction. By ARTHUR RIGG, Engineer, Member of the Society of Engineers and of the Royal Institution of Great Britain. Demy 4to, *copiously illustrated with woodcuts and* 96 *plates*, in one Volume, half-bound morocco, 2*l.* 2*s.*; or cheaper edition, cloth, 25*s.*

This work is not, in any sense, an elementary treatise, or history of the steam engine, but is intended to describe examples of Fixed Steam Engines without entering into the wide domain of locomotive or marine practice. To this end illustrations will be given of the most recent arrangements of Horizontal, Vertical, Beam, Pumping, Winding, Portable, Semiportable, Corliss, Allen, Compound, and other similar Engines, by the most eminent Firms in Great Britain and America. The laws relating to the action and precautions to be observed in the construction of the various details, such as Cylinders, Pistons, Piston-rods, Connecting-rods, Cross-heads, Motion-blocks, Eccentrics, Simple, Expansion, Balanced, and Equilibrium Slide-valves, and Valve-gearing will be minutely dealt with. In this connection will be found articles upon the Velocity of Reciprocating Parts and the Mode of Applying the Indicator, Heat and Expansion of Steam Governors, and the like. It is the writer's desire to draw illustrations from every possible source, and give only those rules that present practice deems correct.

A Practical Treatise on the Science of Land and Engineering Surveying, Levelling, Estimating Quantities, etc., with a general description of the several Instruments required for Surveying, Levelling, Plotting, etc. By H. S. MERRETT. Fourth edition, revised by G. W. USILL, Assoc. Mem. Inst. C.E. 41 *plates, with illustrations and tables*, royal 8vo, cloth, 12*s.* 6*d.*

PRINCIPAL CONTENTS:

Part 1. Introduction and the Principles of Geometry. Part 2. Land Surveying; comprising General Observations—The Chain—Offsets Surveying by the Chain only—Surveying Hilly Ground—To Survey an Estate or Parish by the Chain only—Surveying with the Theodolite—Mining and Town Surveying—Railroad Surveying—Mapping—Division and Laying out of Land—Observations on Enclosures—Plane Trigonometry. Part 3. Levelling—Simple and Compound Levelling—The Level Book—Parliamentary Plan and Section—Levelling with a Theodolite—Gradients—Wooden Curves—To Lay out a Railway Curve—Setting out Widths. Part 4. Calculating Quantities generally for Estimates—Cuttings and Embankments—Tunnels—Brickwork—Ironwork—Timber Measuring. Part 5. Description and Use of Instruments in Surveying and Plotting—The Improved Dumpy Level—Troughton's Level—The Prismatic Compass—Proportional Compass—Box Sextant—Vernier—Pantagraph—Merrett's Improved Quadrant—Improved Computation Scale—The Diagonal Scale—Straight Edge and Sector. Part 6. Logarithms of Numbers—Logarithmic Sines and Co-Sines, Tangents and Co-Tangents—Natural Sines and Co-Sines—Tables for Earthwork, for Setting out Curves, and for various Calculations, etc., etc., etc.

Health and Comfort in House Building, or Ventilation with Warm Air by Self-Acting Suction Power, with Review of the mode of Calculating the Draught in Hot-Air Flues, and with some actual Experiments. By J. DRYSDALE, M.D., and J. W. HAYWARD, M.D. Second edition, with Supplement, *with plates*, demy 8vo, cloth, 7*s.* 6*d.*

The Assayer's Manual: an Abridged Treatise on the Docimastic Examination of Ores and Furnace and other Artificial Products. By BRUNO KERL. Translated by W. T. BRANNT. *With* 65 *illustrations*, 8vo, cloth, 12*s*. 6*d*.

Electricity: its Theory, Sources, and Applications. By J. T. SPRAGUE, M.S.T.E. Second edition, revised and enlarged, *with numerous illustrations*, crown 8vo, cloth, 15*s*.

The Practice of Hand Turning in Wood, Ivory, Shell, etc., with Instructions for Turning such Work in Metal as may be required in the Practice of Turning in Wood, Ivory, etc.; also an Appendix on Ornamental Turning. (A book for beginners.) By FRANCIS CAMPIN. Third edition, *with wood engravings*, crown 8vo, cloth, 6*s*.

CONTENTS:

On Lathes—Turning Tools—Turning Wood—Drilling—Screw Cutting—Miscellaneous Apparatus and Processes—Turning Particular Forms—Staining—Polishing—Spinning Metals—Materials—Ornamental Turning, etc.

Treatise on Watchwork, Past and Present. By the Rev. H. L. NELTHROPP, M.A., F.S.A. *With* 32 *illustrations*, crown 8vo, cloth, 6*s*. 6*d*.

CONTENTS:

Definitions of Words and Terms used in Watchwork—Tools—Time—Historical Summary—On Calculations of the Numbers for Wheels and Pinions; their Proportional Sizes, Trains, etc.—Of Dial Wheels, or Motion Work—Length of Time of Going without Winding up—The Verge—The Horizontal—The Duplex—The Lever—The Chronometer—Repeating Watches—Keyless Watches—The Pendulum, or Spiral Spring—Compensation—Jewelling of Pivot Holes—Clerkenwell—Fallacies of the Trade—Incapacity of Workmen—How to Choose and Use a Watch, etc.

Algebra Self-Taught. By W. P. HIGGS, M.A., D.Sc., LL.D., Assoc. Inst. C.E., Author of 'A Handbook of the Differential Calculus,' etc. Second edition, crown 8vo, cloth, 2*s*. 6*d*.

CONTENTS:

Symbols and the Signs of Operation—The Equation and the Unknown Quantity—Positive and Negative Quantities—Multiplication—Involution—Exponents—Negative Exponents—Roots, and the Use of Exponents as Logarithms—Logarithms—Tables of Logarithms and Proportionate Parts—Transformation of System of Logarithms—Common Uses of Common Logarithms—Compound Multiplication and the Binomial Theorem—Division, Fractions, and Ratio—Continued Proportion—The Series and the Summation of the Series—Limit of Series—Square and Cube Roots—Equations—List of Formulæ, etc.

Spons' Dictionary of Engineering, Civil, Mechanical, Military, and Naval; with technical terms in French, German, Italian, and Spanish, 3100 pp., and *nearly* 8000 *engravings*, in super-royal 8vo, in 8 divisions, 5*l*. 8*s*. Complete in 3 vols., cloth, 5*l*. 5*s*. Bound in a superior manner, half-morocco, top edge gilt, 3 vols., 6*l*. 12*s*.

Notes in Mechanical Engineering. Compiled principally for the use of the Students attending the Classes on this subject at the City of London College. By HENRY ADAMS, Mem. Inst. M.E., Mem. Inst. C.E., Mem. Soc. of Engineers. Crown 8vo, cloth, 2*s*. 6*d*.

Canoe and Boat Building: a complete Manual for Amateurs, containing plain and comprehensive directions for the construction of Canoes, Rowing and Sailing Boats, and Hunting Craft. By W. P. STEPHENS. *With numerous illustrations and 24 plates of Working Drawings.* Crown 8vo, cloth, 7*s*. 6*d*.

Proceedings of the National Conference of Electricians, Philadelphia, October 8th to 13th, 1884. 18mo, cloth, 3*s*.

Dynamo - Electricity, its Generation, Application, Transmission, Storage, and Measurement. By G. B. PRESCOTT. *With 545 illustrations.* 8vo, cloth, 1*l*. 1*s*.

Domestic Electricity for Amateurs. Translated from the French of E. HOSPITALIER, Editor of "L'Electricien," by C. J. WHARTON, Assoc. Soc. Tel. Eng. *Numerous illustrations.* Demy 8vo, cloth, 9*s*.

CONTENTS:

1. Production of the Electric Current—2. Electric Bells—3. Automatic Alarms—4. Domestic Telephones—5. Electric Clocks—6. Electric Lighters—7. Domestic Electric Lighting—8. Domestic Application of the Electric Light—9. Electric Motors—10. Electrical Locomotion—11. Electrotyping, Plating, and Gilding—12. Electric Recreations—13. Various applications—Workshop of the Electrician.

Wrinkles in Electric Lighting. By VINCENT STEPHEN. *With illustrations.* 18mo, cloth, 2*s*. 6*d*.

CONTENTS:

1. The Electric Current and its production by Chemical means—2. Production of Electric Currents by Mechanical means—3. Dynamo-Electric Machines—4. Electric Lamps—5. Lead—6. Ship Lighting.

The Practical Flax Spinner; being a Description of the Growth, Manipulation, and Spinning of Flax and Tow. By LESLIE C. MARSHALL, of Belfast. *With illustrations.* 8vo, cloth, 15*s*.

Foundations and Foundation Walls for all classes of Buildings, Pile Driving, Building Stones and Bricks, Pier and Wall construction, Mortars, Limes, Cements, Concretes, Stuccos, &c. 64 *illustrations.* By G. T. POWELL and F. BAUMAN. 8vo, cloth, 10*s*. 6*d*.

Manual for Gas Engineering Students. By D. LEE. 18mo, cloth 1*s.*

Hydraulic Machinery, Past and Present. A Lecture delivered to the London and Suburban Railway Officials' Association. By H. ADAMS, Mem. Inst. C.E. *Folding plate.* 8vo, sewed, 1*s.*

Twenty Years with the Indicator. By THOMAS PRAY, Jun., C.E., M.E., Member of the American Society of Civil Engineers. 2 vols., royal 8vo, cloth, 12*s.* 6*d.*

Annual Statistical Report of the Secretary to the Members of the Iron and Steel Association on the Home and Foreign Iron and Steel Industries in 1884. Issued March 1885. 8vo, sewed, 5*s.*

Bad Drains, and How to Test them; with Notes on the Ventilation of Sewers, Drains, and Sanitary Fittings, and the Origin and Transmission of Zymotic Disease. By R. HARRIS REEVES. Crown 8vo, cloth, 3*s.* 6*d.*

Well Sinking. The modern practice of Sinking and Boring Wells, with geological considerations and examples of Wells. By ERNEST SPON, Assoc. Mem. Inst. C.E., Mem. Soc. Eng., and of the Franklin Inst., etc. Second edition, revised and enlarged. Crown 8vo, cloth, 10*s.* 6*d.*

Pneumatic Transmission of Messages and Parcels between Paris and London, viâ Calais and Dover. By J. B. BERLIER, C.E. Small folio, sewed, 6*d.*

List of Tests (*Reagents*), arranged in alphabetical order, according to the names of the originators. Designed especially for the convenient reference of Chemists, Pharmacists, and Scientists. By HANS M. WILDER. Crown 8vo, cloth, 4*s.* 6*d.*

Ten Years' Experience in Works of Intermittent Downward Filtration. By J. BAILEY DENTON, Mem. Inst. C.E. Second edition, with additions. Royal 8vo, sewed, 4*s.*

A Treatise on the Manufacture of Soap and Candles, Lubricants and Glycerin. By W. LANT CARPENTER, B.A., B.Sc. (late of Messrs. C. Thomas and Brothers, Bristol). *With illustrations.* Crown 8vo, cloth, 10*s.* 6*d.*

The Stability of Ships explained simply, and calculated by a new Graphic method. By J. C. SPENCE, M.I.N.A. 4to, sewed, 3*s.* 6*d.*

Steam Making, or Boiler Practice. By CHARLES A. SMITH, C.E. 8vo, cloth, 10*s.* 6*d.*

CONTENTS:

1. The Nature of Heat and the Properties of Steam—2. Combustion.—3. Externally Fired Stationary Boilers—4. Internally Fired Stationary Boilers—5. Internally Fired Portable Locomotive and Marine Boilers—6. Design, Construction, and Strength of Boilers—7. Proportions of Heating Surface, Economic Evaporation, Explosions—8. Miscellaneous Boilers, Choice of Boiler Fittings and Appurtenances.

The Fireman's Guide; a Handbook on the Care of Boilers. By TEKNOLOG, föreningen T. I. Stockholm. Translated from the third edition, and revised by KARL P. DAHLSTROM, M.E. Second edition. Fcap. 8vo, cloth, 2*s.*

A Treatise on Modern Steam Engines and Boilers, including Land Locomotive, and Marine Engines and Boilers, for the use of Students. By FREDERICK COLYER, M. Inst. C.E., Mem. Inst. M.E. *With* 36 *plates.* 4to, cloth, 25*s.*

CONTENTS:

1. Introduction—2. Original Engines—3. Boilers—4. High-Pressure Beam Engines—5. Cornish Beam Engines—6. Horizontal Engines—7. Oscillating Engines—8. Vertical High-Pressure Engines—9. Special Engines—10. Portable Engines—11. Locomotive Engines—12. Marine Engines.

Steam Engine Management; a Treatise on the Working and Management of Steam Boilers. By F. COLYER, M. Inst. C.E., Mem. Inst. M.E. 18mo, cloth, 2*s.*

Land Surveying on the Meridian and Perpendicular System. By WILLIAM PENMAN, C.E. 8vo, cloth, 8*s.* 6*d.*

The Topographer, his Instruments and Methods, designed for the use of Students, Amateur Photographers, Surveyors, Engineers, and all persons interested in the location and construction of works based upon Topography. *Illustrated with numerous plates, maps, and engravings.* By LEWIS M. HAUPT, A.M. 8vo, cloth, 18*s.*

A Text-Book of Tanning, embracing the Preparation of all kinds of Leather. By HARRY R. PROCTOR, F.C.S., of Low Lights Tanneries. *With illustrations.* Crown 8vo, cloth, 10*s.* 6*d.*

JUST PUBLISHED.

Crown 8vo, cloth, 480 pages, with 183 illustrations, 5*s.*

WORKSHOP RECEIPTS, THIRD SERIES.

BY C. G. WARNFORD LOCK.

Uniform with the First and Second Series.

SYNOPSIS OF CONTENTS.

Alloys.	Indium.	Rubidium.
Aluminium.	Iridium.	Ruthenium.
Antimony.	Iron and Steel.	Selenium.
Barium.	Lacquers and Lacquering.	Silver.
Beryllium.	Lanthanum.	Slag.
Bismuth.	Lead.	Sodium.
Cadmium.	Lithium.	Strontium.
Cæsium.	Lubricants.	Tantalum.
Calcium.	Magnesium.	Terbium.
Cerium.	Manganese.	Thallium.
Chromium.	Mercury.	Thorium.
Cobalt.	Mica.	Tin.
Copper.	Molybdenum.	Titanium.
Didymium.	Nickel.	Tungsten.
Electrics.	Niobium.	Uranium.
Enamels and Glazes.	Osmium.	Vanadium.
Erbium.	Palladium.	Yttrium.
Gallium.	Platinum.	Zinc.
Glass.	Potassium.	Zirconium.
Gold.	Rhodium.	

London: E. & F. N. SPON, 125, Strand.

New York: 12, Cortlandt Street.

WORKSHOP RECEIPTS,

FOURTH SERIES,

DEVOTED MAINLY TO HANDICRAFTS & MECHANICAL SUBJECTS.

BY C. G. WARNFORD LOCK.

250 Illustrations, with Complete Index, and a General Index to the Four Series, 5s.

Waterproofing—rubber goods, cuprammonium processes, miscellaneous preparations.

Packing and Storing articles of delicate odour or colour, of a deliquescent character, liable to ignition, apt to suffer from insects or damp, or easily broken.

Embalming and Preserving anatomical specimens.

Leather Polishes.

Cooling Air and Water, producing low temperatures, making ice, cooling syrups and solutions, and separating salts from liquors by refrigeration.

Pumps and Siphons, embracing every useful contrivance for raising and supplying water on a moderate scale, and moving corrosive, tenacious, and other liquids.

Desiccating—air- and water-ovens, and other appliances for drying natural and artificial products.

Distilling—water, tinctures, extracts, pharmaceutical preparations, essences, perfumes, and alcoholic liquids.

Emulsifying as required by pharmacists and photographers.

Evaporating—saline and other solutions, and liquids demanding special precautions.

Filtering—water, and solutions of various kinds.

Percolating and Macerating.

Electrotyping.

Stereotyping by both plaster and paper processes.

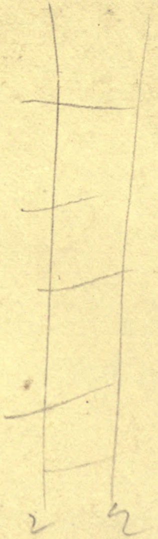
Bookbinding in all its details.

Straw Plaiting and the fabrication of baskets, matting, etc.

Musical Instruments—the preservation, tuning, and repair of pianos, harmoniums, musical boxes, etc.

Clock and Watch Mending—adapted for intelligent amateurs.

Photography—recent development in rapid processes, handy apparatus, numerous recipes for sensitizing and developing solutions, and applications to modern illustrative purposes.



4